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Some chemical properties of the humus layer in Swedish natural soils

by

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Introduction

There are numerous investigations on the chemistry of the humus layer of natural terrestrial soils in Scandinavia (see, e.g., Hesselman 1926, Lindquist 1938 a and b, Mattson & Koutler-Andersson 1941—54, Arnborg 1943, Julin 1948, Malmström 1949, Sjörs 1954, Låg & Mork 1959, Linnermark 1960). A large number of peats have also been analysed, although mainly in areas drained for cultivation; thus it is difficult to use the wealth of figures obtained (see Osvald 1937 pp. 219—232). These data lack a suitable basis for comparison, as some of them are given only as parts per unit dry weight, others as tons per ha (to a depth of 20 cm). Malmström's values, and some of the others, are computed per unit of humus content. — Very numerous data are available from virgin peats in Finland (Puustjärvi 1952, 1955, 1956, 1957, 1959, 1960; Kaila 1956 a, b, c, 1958; Kaila & Kivekäs 1956; Kaila, Kivekäs, Virri & Kivinen 1957; Kivekäs & Kaila 1957; Kivekäs 1958; etc.).

During the present investigation I was trying to find a method of sampling and a way of expressing the results that could allow a fairly sound comparison of the analytical data for ecological purpose both within and between the different kinds of humus — mor, mull, and peat of varying structure. By sampling the humus layer under a wide variety of vegetation types, material was collected illustrating the relation between vegetation, humus types and some physical and chemical properties of the latter. A procedure was worked out and various analytical methods tested. An attempt was also made to compare analyses on fresh and dried aliquots of the same soil sample. However, the possibilities of working up soils immediately were limited, so nearly half the soils have only been analysed in the dry state (in some cases fresh pH was obtained). For various reasons, e.g. insufficient quantity of sample, the analytical scheme was not applied in full to all samples.

Different analytical methods of varying accuracy were used in several cases, especially for Ca. In spite of the tentative character of the investigation, the figures obtained may be regarded as sufficiently comparable to justify their publication. There is a discouraging lack of good reproducibility in chemical humus analysis. (The apparent exception of pH is mainly

due to the logarithmic character of the pH scale.) High accuracy is however of little value when one is dealing with a heterogeneous material so easily subject to unpredictable changes as humus, and is unnecessary for ordinary ecological comparisons.

Chemical factors affect plants according to both intensity (activity, tension) and capacity (quantity). Two ways of expressing concentrations have been chosen, viz. per unit of loss on ignition, and per unit of soil volume. The former gives a fairly good representation of the intensity of the chemical factor in question, because mineral grains present in the humus layer may largely be regarded as a comparatively inactive admixture to the humus colloids. Possibly a still better intensity expression for an exchangeable cation is the ratio to total exchangeable cations (Jenny & Ayers 1939), but the accuracy of the latter value is, in the present investigation, frequently too low to permit this calculation.

Concentration per unit soil volume indicates roughly the magnitude of the supply in the soil, even if it is in many cases only partly available to plants. But as the contents of most nutrients decrease downward in the soil profile to differing degrees, an integrated figure for the rhizosphere or the whole soil profile would be preferable for this purpose. Cf. Gjems, Holstener-Jörgensen, Karlsson, C. O. Tamm & Troedsson 1960. It would require the analysis of at least 4—6 samples in each profile and is thus feasible only in special investigations or for laboratories with great resources. The analysis of a whole soil core is a useful substitute in arable soils, but natural soils are usually too strongly stratified for this simplified method.

A single sample, even if taken from the most representative and presumably most active part of the humus layer, cannot give evidence of the development of the humus. Even the analysis of a sequence of samples through the humus layer would be inadequate for this purpose. It is hardly feasible to study the dynamic aspect of humus formation by chemical methods alone. Humus stratification is not simply formation of consecutive strata (Romell 1945). The dynamism must therefore also be investigated by other methods than pure analysis, e. g. micro-structural and microbiological investigation and studies of experimental or historical evidence.

As objections against the use of ignition loss for calculations, one may think of the presence of inorganic colloids acting as ion exchangers, and possibly of minerals that will dissolve during certain analytical operations. In both cases the results on the ignition loss basis will be particularly high in soils of low humus content. The exchange capacity of clay minerals is smaller than that of humus, by weight, and the content of colloidal clay is very much less than the humus content, except in the few clayey mull samples. In clayey mulls of very low ignition loss, results may on this

account appear much too high, if expressed on the ignition loss basis. In humus-rich or sandy mulls the clay effect is less. It would cause great difficulty to determine the exchange capacity of the mineral component separately, and the results would be rather unreliable, because in the natural state clay and humus cooperate closely in ion adsorption. Moreover, collodial inorganic matter contributes to some extent to the ignition loss, which counteracts the effect mentioned above.

The effect of soluble minerals, if present, is possibly considerable regarding total phosphorus, which is determined by extraction with hydrochloric acid of the residue after ignition. There are a few very high total phosphorus values (Nos. 208, 128) which may be explained this way. Influence of animals (bird droppings, etc.) is also possible, in particular in hardwood groves. However, any acid-soluble phosphate present in the root zone of plants may be regarded as available in the long run. — Regarding $CaCO_3$ see p. 13.

These considerations involve no objektions when the contents are expressed on the volume basis. Of the two samples mentioned, No. 208 (Table 2, Örup elm-wood) is rich in clay; the values for phosphorus and cations become more moderate if expressed on the volume basis. In No. 128 (Table 3) the volume was not determined but it seems likely that figures on the volume basis would be still higher. This sample is fairly rich in humus, and a clay mineral effect would therefore be small. Mineral or animal phosphate may well be present in these and some other cases.

The field work was mainly done in 1953—55, in different parts of Sweden visited mainly for other purposes. Additional samples were collected in 1959. Mrs. Gunnel Sjörs, fil. kand., aided in the recording of vegetation and soil profiles. The analyses were carried out in the Laboratory of Plant Ecology of the Botanical Museum, Lund, and later on at the Royal School of Forestry, Stockholm 51, where the study was completed. At Lund, technical assistance was given by Miss Signe Kerwall, Mrs. Gunn Hansson and Mrs. Inna Mathiesen. In an early stage of the investigation, the Beckman spectrophotometer and part of the Kjeldahl apparatus of the Institute of Plant Physiology, Lund, were kindly placed at my disposal by Prof. Hans Burström. Some commercial analyses were performed at Statens lantbrukskemiska kontrollanstalt (laboratories at Kristianstad and Stockholm). I also owe my special thanks to Mr. Nils Malmer, fil. lic., Lund, Prof. Carl Olof Tamm, Stockholm, and Dr. Eville Gorham, Toronto, for aid and discussion. The manuscript was kindly revised by the latter.

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Distinction of humus types

The most reliable criteria of the distinction between mor and mull are not the chemical properties as such but the bio-ecological conditions on which they depend (Romell 1932, 1934, 1935, 1944, 1953, Stålfelt 1960 pp. 143—148). Neither chemical nor micro-ecological conditions can be readily determined in the field, but a system that allows direct designation of the humus type is indispensable in field studies. We therefore have to use pedo-morphological appearance for the field determination. In the present investigation the samples have not been sorted according to the results of the analyses, but classified without regard to the latter.

The humus layer was regarded and classified as a whole, according to its pedo-morphology. The classification was always done in the field, after the upper part of the soil profile had been examined and sampled. The three collective types of humus layer to which all samples have been referred are mor (duff, raw humus), mull, and peat. A number of the samples represent aberrant types only referable to the main groups with some difficulty. Types not at all referable to these groups also exist under some Swedish natural vegetation but have not been studied.

Humus accumulated as growing deposits in wet sites is regarded as peat (although accumulation of peat can be interrupted, so the deposits are not always growing at present). The other types of humus do not accumulate after equilibrium between deposition and decomposition is reached, except on certain sites in very cool or wet climates, and are developed on terrestrial (or semi-terrestrial) sites.

In mull the organic component is closely united with the fine mineral fractions, but the amount of the latter may be small in many cases. The colloid structure in mull is aggregate (not always coarsely, as in the typical crumb structure due to large earthworms). Poorly decomposed organic material is visibly present only to a small extent, except sometimes on the surface. In contrast, mor shows poor incorporation of mineral grains (if present), a non-aggregate colloid state, and usually much poorly decomposed organic fragments except in the lower H horizon (if present). The properties of mor are largely due to fungal decomposition and presence of living and more or less fragmentated dead mycelia, whereas mull is rich in bacteria frequently embedded in slimy capsules of gelatinous excreta. The different proportions of adsorbed monovalent and bivalent cations in mor and mull, and also the different secondary products from the decomposition of high-molecular substances, account to some extent for the difference in colloid structure.

Thus the pedo-morphological criteria are strongly related to the bio-

ecological properties. Their relationship to the chemical properties, long well-known, is also clearly demonstrated in the present investigation.

Most of the mor samples consist of more or less pure humus with insignificant mineral content. Some contain mineral grains, chiefly sand, but are still essentially mor. No. 130 is a subalpine humus soil intermediate between mor and bog hummock peat. No. 186, from oak forest, is structurally intermediate to mull; however it proved to be a more typical mor chemically.

Mull is used here for various kinds of »mild humus» that are not mor, but may perhaps be classed beside and not within the mull proper in a more elaborate system of humus layer types.

The mull type of humus layer is thus not only represented by »typical» mulls of fairly low humus percentage (usually 8—24 % ignition loss) and with a well developed crumb structure due to large earthworms. There are good reasons to include among the mulls also types of humus layer deviating either in less well-developed crumb structure (cf. Sjörs 1954 p. 68), or in fairly high humus percentage by weight (ibid. p. 70). These two deviating characters may be combined, but there also exist mulls with poor structure and a low or medium content of humus, as well as highly humous mulls with excellent crumb structure. Most of these cases must be regarded as representing sub-types of mull, not as transitions to mor pedo-morphologically. Also their chemical properties fall within the range of variation of mull and frequently outside that of most Swedish mors. This evident from the present material as well as from the determinations in Sjörs 1954 (Table 13 p. 120).

Mull, as understood here, includes also for instance subalpine mild humus (No. 141; cf. Du Rietz 1945); a peculiar dark humus (No. 154) developed over weathered alum shales and containing fossil carbonized organic matter; thin dark humus under meadow vegetation on dry rocks (Nos. 175, 178, 126); and the types designated »fat mull» and »raw mull» by Lindquist (1938 a and b) and Julin (1948).

Several mull samples contained as much as about 40—60 % combustible matter; on the other hand, a sandy mull showed as little as 7 % ignition loss. It is emphasized that, for Sweden at least, neither the volume weight nor the ignition loss or humus content should decide whether a sample should be denoted as mor or mull.

The statements above self-evidently do not exclude the existence of true transitions between mor and mull. In the present material, the mor 186 (Table 1), from oak forest, and the mull 188 (Table 2; possibly also No. 200), from beech forest, are examples of transitional cases.

Sampling

Simple sampling cylinders were made from ordinary thinwalled tins cut down to a height of 4 or 2 cm. The lower edge was sharpened as much as possible to cut small roots, and straightened if damaged by hard objects. Such a tool is easy to prepare and cheap to replace when worn out. After the vegetation and litter had been removed, the sampler was pressed down with a rotating movement. If moderate pressure was not sufficient, the sampler was helped down by cutting vertically around its edge with a knife. When filled, the sampler was dug up and the soil core was cut off level at its lower end with the knife. The contents were then transferred to a polythene bag. This was repeated 3—5 times for each site, and the primary samples were mixed.

The sample was usually taken between 2 and 6 cm below the surface in peats and mulls (in thin layers, between 1 and 5 cm or between 0 and 4 cm). In thin mors it was often necessary to take a larger number of 2 cm slices. The accuracy of the volume is low in samples of mors and some loose peats. The volume of the total sample need not exceed 0.3 l for mulls but this is insufficient for mors and peats, at least 0.5 l being desirable.

Treatment of samples and water determination

In some cases it was of interest to know the original water content of a sample, for instance if it was taken at saturated field capacity or at wilting point. The water content of all samples extracted in the fresh state had also to be determined. Samples of wet peat could safely be packed in airtight polythene bags for some time, but not samples of moist terrestrial humus. If water content is desired for such a sample, it should be weighed almost at once; if not dealt with immediately, it should be kept in a container that is not completely airtight, to prevent anaerobic fermentation. All fresh samples ought to be stored in a cool place, preferably a refrigerator, and analyzed without much delay. Mors, and generally humus from dry sites, seem to be less liable to change than damp mulls, as also found by Gorham (1953 a, p. 128).

The sample was weighed and well mixed, and portions were taken out for analysis of fresh material (one subsample for pH and one for each extraction with electrolyte solution). Large roots and pebbles were removed.

The remains were weighed again. From the ratio between the two weighings and the original volume, the volume of the remaining part was calculated. The remains were then spread in a thin layer, dried quickly at about 20—30° C and weighed as air-dry. The loss in weight gives the water content. Then the remaining part of the sample was disintegrated and worked through a 2 mm sieve. The roots and gravel not passing through were discarded. If pebbles and gravel were present, their weight and volume were subtracted from those of the sample before calculations. No correction was made for roots, but large roots and dense root mats were avoided during sampling.

The material passing the sieve was mixed and used for analyses of dried material, including ignition, determination of phosphorus and micro-Kjeldahl combustion for nitrogen.

A modification has been used for peats from Ireland (to be published in a future paper jointly with E. Gorham). The fresh peat was placed in a hydraulic filtering press and part of the water was squeezed from it and analysed separately.

Analytical remarks

Water extract pH. To one volume of soil enough water was added to make up to a total of two volumes (Knutson in Malmström 1949). After shaking for several hours and filtering, pH was determined in the filtrate with a glass electrode.

Dried soil frequently gave a lower pH than the same soil extracted fresh (Fig. 1). For unknown reasons this occurred especially strongly in the samples taken during the very dry summer of 1959. The effect is most frequent in mull and peat. Pearsall & Lind (1941) and Pearsall (1952) reported increasing acidity on drying of peats, ascribed to effects of oxidation. Kivekäs (1958), on the contrary, found a rise in pH of acid peat after drying and grinding, possibly due to release of H_4N^+ ions.

Brown's metod. Although this method has been described in earlier papers (Brown 1943, Gorham 1953 a p. 129, Sjörs 1954 pp. 72—74, Malmer in Malmer & Sjörs 1955 p. 51), a few more words ought to be said about its chemical significance. According to this method, exchangeable hydrogen and metal ions are determined by the pH displacement in extracts made with normal ammonium acetate and acetic acid solutions, respectively.

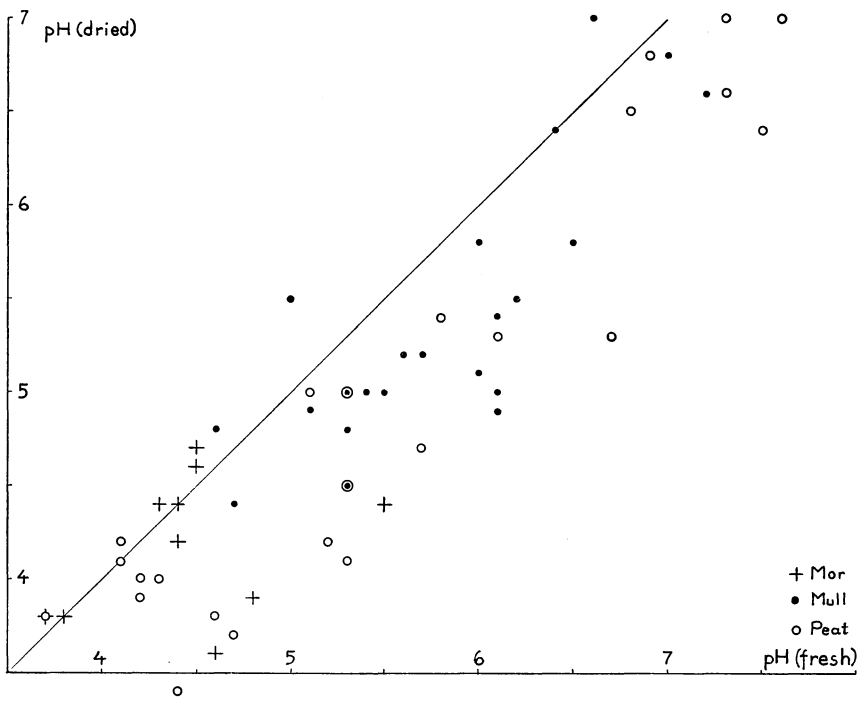

Fig. 1. pH in water extracts of fresh and dried portions of the samples. The dried samples are frequently considerably more acid.

Ammonium acetate solution shows two equilibria:

$$H_4N^+ \leftrightharpoons H_3N + H^+; \qquad H^+ + CH_3COO^- \leftrightharpoons CH_3COOH$$

Both dissociations have almost exactly the same dissociation constant. The solution is thus neutral, but tends to lose more ammonia than acetic acid on standing. The stock solution should therefore be adjusted closely to pH 7.00 before using (it is not necessary to keep it exactly at normal concentration). It should be kept in coated or plastic bottles, because it takes up sodium from ordinary glass bottles.

When this strong solution is in contact with small amounts of humus, all kinds of ions reversibly adsorbed will be almost quantitatively exchanged with H_4N^+ or CH_3COO^- ions. The exchange capacity for anions is very low in humus, so mainly cations are released. If H^+ ions are released, most of them will combine with CH_3COO^- ions as stated above, which favours the completeness of the exchange. However, a small part of the H^+ ions released remain free in equilibrium with the excess acetic acid, and pH is therefore lowered to a small but easily measurable extent. The decrease in pH is then compared with the decrease caused by adding small amounts of H^+ as 0.1 N HCl to a portion of the pure ammonium acetate solution.

Metal ions are also released by the ammonium acetate solution. The solution thus loses H_4N^+ ions also in exchange for metal ions, but the effect of this on the equilibrium is negligible if small amounts of humus are used. Only in cases where there are no or very few exchangeable H^+ ions but a great quantity of metal ions, could the effect be a measurable rise in pH; but in most cases when such a rise occurs it is mainly or partly due to dissolved carbonate (see below).

Adsorbed anions decrease the acetate concentration only slightly when released, and are without measurable effect. Soluble neutral salts in low concentrations do not affect the equilibrium.

If $CaCO_3$ is present, it will slowly dissolve, because carbonate ions are used up:

$$H_4N^+ \leftrightarrows H_3N+H^+; \quad H^+ + CO_3^{2-} \leftrightarrows HCO_3^-$$

This leads to a rise in pH. Therefore, soils containing $CaCO_3$ show > 100 % »neutralization». The attack on $CaCO_3$ is not vigourous and often incomplete, and the total content of Ca (exchangeable and carbonate) cannot be estimated from the extracts in these cases.

Normal acetic acid is weakly dissociated and shows a pH of 2.3. Its H^+ ion activity is thus only 0.005 and it is not very powerful as an ion exchange solution. However, the H^+ ions are strongly adsorbed by humus, in exchange for metal ions. Part of the adsorbed H^+ ions are replaced from the reaction

$$CH_3COOH \leftrightarrows CH_3COO^- + H^+$$

The decrease in H^+ ion activity is thus smaller than, but dependent on the amount of exchanged or dissolved metal ions in excess over dissolved anions of acids stronger than acetic acid. According to Brown, this metal ion excess is estimated from the rise in pH, by means of pH values obtained during addition of 0.1 N NaOH to a portion of the pure acetic acid solution. In the case of a calcareous sample, acetic acid will usually dissolve small grains of $CaCO_3$ completely; if so, this calcium will add to the exchanged cations.

It follows from the above that the humus sample used for extraction should be small. Its humus content should not be much more than 1 g for 50 ml of extractant. However, the humus and water content can only be roughly guessed at this stage of the analysis of a fresh sample; therefore the amount of humus taken will vary considerably. Using fresh soils, the amounts of both soil and extractant are preferably doubled because it is difficult to take out very small samples from fresh soil in a representative way.

After filtering (centrifuging is perhaps preferable) pH was determined very carefully (two decimals) in small parts of the extracts, and fitted in

on pH curves from newly made acid or base titrations of the extractants. The percentage of »neutralization» (Sjörs 1954 pp. 73, 130), or percentage metal ion saturation (Piper 1950 p. 154), could more precisely be defined as the percentage of the exchange complex saturated with metal cations in excess over anions. When determined by Brown's method it is equal to:

$$\frac{100 \cdot \text{acetic acid titration value}}{\text{sum of both titration values}}$$

or

$$\frac{100\ (\text{exchangeable metal ions} - \text{exchangeable anions})}{\text{total exchangeable cations} - \text{exchangeable anions}}$$

The quantity of adsorbed anions is always small and affects this value appreciably only in case of very low metal ion content.

The differences between the quantities of metal ions extracted by the two extractants were mostly irregular. Deviations were considerable in a few cases. It is likely that such factors as unequal structure of the soil, presence of roots, local activity of microorganisms, etc., are largely responsible for them, beside analytical errors.

There are also often differences between the quantities of ions extracted by the same extractant from fresh and from dried humus. Frequently a stronger displacement of the acetic acid pH took place when rich mull was extracted in the dried state, and thus a higher value for metal ions was found (Fig. 2). This is difficult to explain, because the dominant metal ion in the acetic acid extracts, Ca^{2+}, did not increase upon drying the mull humus. A possible explanation may be that some anions (organic?) were rendered non-exchangeable or destroyed by the drying, or that some strong acidoids were rendered inactive. There was no sure influence of drying the humus on the ammonium acetate pH, although deviations occurred; the quantity of exchangeable H^+ was considerably lowered by drying in a few cases. The total exchange capacity for cations (in excess over anions) was frequently somewhat increased by drying. In peats, according to Puustjärvi (1956), this value is dependent on the way it is determined, as well as on the fresh or dry state and the kind of peat (pp. 413, 425, 426, 439, 444, etc.). Cp. below, p. 21.

In a number of mulls and mors drying increased the »percentage of neutralization». Nevertheless, in the water extracts mentioned above (p. 11), pH became lower with dried soil in a great majority of cases (Fig. 1).

The extractants used by me (acetic acid and ammonium acetate in normal solution) may be regarded as less efficient than 0.5 N barium acetate used by Puustjärvi (1956, 1957) to determine the exchange capacity of the H-peats obtained by the two methods mentioned below (p. 21). For instance,

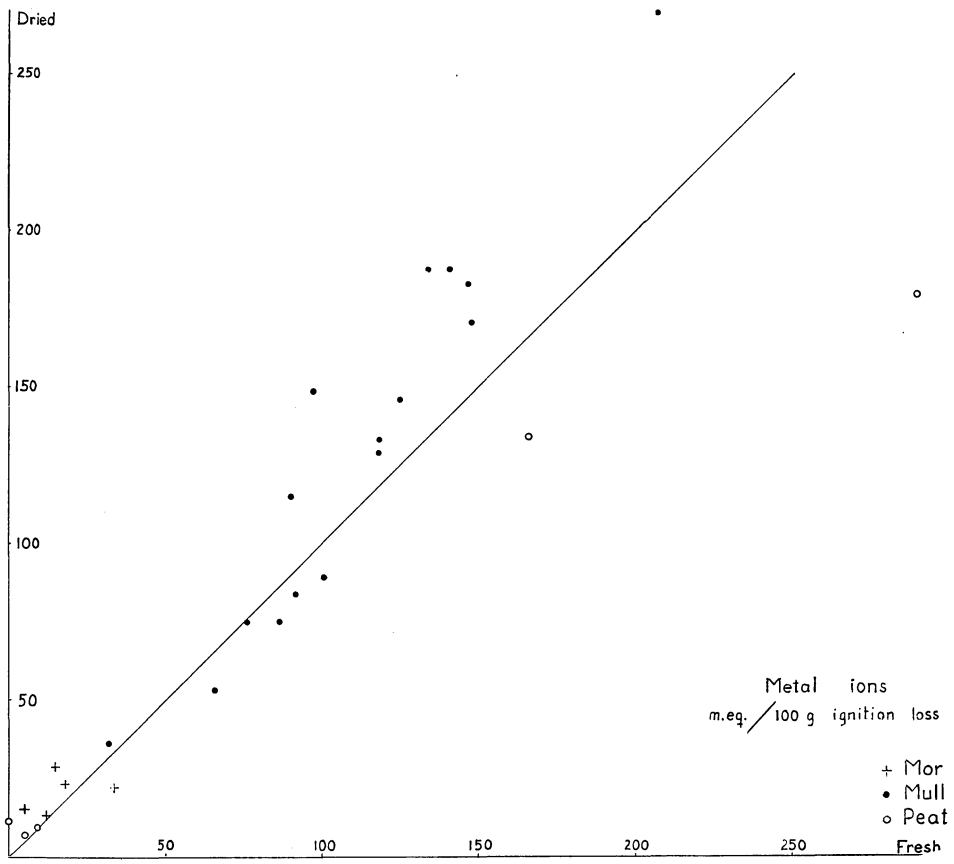

Fig. 2. Extractable metal ions, determined by acetic acid pH displacement with fresh and dried portions of the samples, on ignition loss basis.

it has been stated that 1 N ammonium chloride is inferior to barium chloride (Kaila & Kivekäs 1956 pp. 238, 241; Kivekäs & Kaila 1957 pp. 47—48). It seems safer, after all, to speak of extractable cations instead of exchangeable cations.

Metal ions were determined in other aliquots of the filtrates. Owing to risk of fungal growth, these can be stored only for a week or two at room temperature but for some months in a refrigerator.

Calcium. Ca was determined as oxalate (permanganate titration), by flame photometry (the results may be slightly low owing to very small amounts of sulfate and phosphate present), or by versenate titration. The last method is preferable because Mg can also be determined, but this method was used on only a few of the samples.

Calcium was extracted from fresh humus about equally well with both extractants. Only in thin very Ca-rich peats developed above aquatic deposits of $CaCO_3$, acetic acid was apparently much more powerful, but these soils are extremely unequal in composition, containing small lumps and grains of $CaCO_3$ in the lower parts of the samples. In a number of samples, Ca was less well extracted from dried than from fresh humus, and this was especially the case using ammonium acetate on Ca-rich peat. Acetic acid was very inefficient in extracting Ca from a few dried soils (mainly peats) low in Ca (no determinations on fresh material are available for comparison). However, there are also cases of poor dried mors from which acetic acid extracted considerably more Ca than did ammonium acetate.

The methods used are not suitable for soils containing $CaCO_3$. In such soils, it is very difficult to evaluate the exchange capacity or the part of it occupied by exchangeable Ca^{2+} ions. If really needed, total Ca and CO_2 can be determined, but for comparative ecology a humus soil found to contain calcium carbonate is usually well enough characterized by this fact, since the quantity of a slightly soluble solid has in itself little effect on plants.

Magnesium. Mg was determined in a few samples by versenate titration.

Sodium. Extractable Na was determined by flame photometry (first a Beckman flame spectrophotometer and later a Kipp & Zonen flame photometer was used; a few determinations were made commercially). Sodium is generally very low, and as blank values were in a few cases considerable the irregularities found may partly be influenced by analytical errors. Use of high quality chemicals and plastic bottles is recommended. In wet peats, an appreciable part of the Na^+ found is actually in aqueous solution (Malmer in Malmer & Sjörs 1955 p. 70), but the major part is adsorbed, even near the sea (unpublished data from Ireland, obtained jointly with E. Gorham). Exceptions, of course, are the true saline soils, and probably some fertilized soils.

Potassium. K was determined in the same way as Na. It was about equally extracted by acetic acid and ammonium acetate. Presence of roots may affect the K^+ values, because they probably contain much more K than does humus. A better release from dead than from still living rootlets is perhaps a cause of the often somewhat higher K^+ values for dried soil. Potassium extraction according to Egnér (1940; K. Lantbruksstyrelsen 1950) was made on some of the dried samples; the values are most frequently slightly lower than those with acetic acid or ammonium acetate solutions as extractants.

Phosphorus. Total P was determined after combustion of a subsample of the dried sample. Also soluble P was determined on the dried sample by the acid lactate extraction carried out commercially according to Egnér, Köhler & Nydahl (1938; K. Lantbruksstyrelsen 1950). Generally only a small fraction of the total P was soluble in Egnér's lactate solution. With few exceptions, the humus soils studied were low in P, but the differences proved to be greater in total P content than in the lactate soluble P. On an average, phosphorus thus tends to be more soluble when it is scarce. These conditions are further discussed under the various kinds of humus.

A few determinations of P were also made in the ammonium acetate extracts. The results, which are not published, were rather variable, more P being dissolved from the more acid samples.

Nitrogen. Total N was determined by the micro-Kjeldahl method on the dried samples, usually in duplicates. To each subsample 1.1 ml conc. H_2SO_4 and about 0.40 g K_2SO_4, 0.04 g $CuSO_4$ and 0.03 $HgSO_4$ were added; digestion was continued for 3 hours after clearing. Judging from the duplicates the precision is about $\pm$ 0.1 g N in 100 g ignition loss or in one litre of soil (probable error greater in soils poor in humus). Macro determination would have given a better precision.

Ignition loss. Portions of the dried, sifted soil were dried at 105° C, weighed cool, and slowly ignited at dark red heat (about 550° C). Ignition loss was expressed as percentage of the oven-dry sample, whereas the other values were calculated from the weight in the air-dry state, an inconsistency (of little significance) affecting only those values that are presented in the Tables on the ignition loss (»humus content») basis. As the samples are always much richer in organic matter than in other colloidal or hydrated substances, or carbonates, that may lose in weight during ignition, the loss on ignition represents the content of organic matter fairly well in these samples. Some fragment of rootlets, microorganisms, etc. are included in the organic matter, which thus does not consist entirely of »humus» in a strict sence.

Concluding analytical remarks. To save time, the analysis of the acetic acid extract can be omitted (after its pH has been taken). If the ammonium acetate extract is analysed for all major cations (including also Mg^{2+}), an acetic acid extract need not be made at all. This modified procedure was followed in 1959 in the extraction of fresh samples (those with low numbers). The sum of metal ions, and therefore also the exchange capacity for cations and the percentage of »neutralization», acquire slightly different significance when determined in this way, which may be of importance in

cases of very low »neutralization» (see p. 23). Therefore only values obtained by acetic acid extraction have been entered in the Tables.

Extraction of the dried sample can of course be omitted if the soil has been extracted fresh, but it is always necessary to dry the sample to obtain dry weight, loss on ignition, total N, total P, etc.

On the other hand, exchangeable ions need to be determined on fresh material only in the case of waterlogged or otherwise very wet soils, which do not dry up in nature and are thus probably strongly and more or less irreversibly changed on drying and exposure to oxygen. Fresh soil is preferable also in other cases, and it is rather a dangerous habit of soil analysts to work exclusively with dried samples. For water extract pH, in any case, fresh soil ought to be used, in particular in the investigation of peats.

If time is available, duplication of the extraction of fresh soil is recommended. Equal volumes of the extracts could then be mixed for the determination of metal ions.

Results

The nitrogen, phosphorus, pH and cation values are given in Tables 1—4. In each Table, figures are given on both an ignition loss (humus content) and a volume basis. The values on a dry weight basis are not given but can easily be backcalculated, if desired, using either the loss on ignition, or the dry weight of one litre of soil.

Mor

Table 1 deals with mor. All mors are fairly acid (pH of water extract usually below 4.5) and show a low percentage of »neutralization» (8—34 %), which in several cases is equally low as in ombrotrophic bog peat, and well below nearly all values from mull (Fig. 7 p. 42). The N content of their humus is low (never over 3 %), although the extremely low values often found, particularly in the north, e.g. by Hesselman (1926 pp. 301—305) and Malmström (1949 p. 108), are lacking in the present material. The nitrogen stored in the humus layer is generally about half as large in North Sweden than in the south of the country, corresponding forest vegetation types being compared (Romell in C. O. Tamm 1959, p. 517). On the other hand, values from mor in Britain (Gorham 1953 a) are frequently higher. Total metal ions in excess over anions, and exchangeable Ca^{2+} are

also low, but variable (highest values 36 m.eq. and 26 m.eq., respectively, per 100 g of humus). Contrary to the conditions in mull, the total extractable cations (i.e. exchange capacity for cations, as determined) are usually less than 100 m.eq. per 100 g of humus.

Two samples from *Calluna* heath on gneiss rock, on the Kroppefjäll hills of prov. Dalsland, show high values for extractable cations, as well as nitrogen and total phosphorus, in all these respects resembling mull.

Of the three samples from »Skanörs ljung», a damp moor on poor quartz sand near the sea in S.W. Skåne, the one taken next to the sea shore shows fairly high values for N, Ca^{2+} and Na^{+}. But it is notable that Na^{+} is still a very subordinate ion of the exchange complex, in spite of the supply by spray from the sea.

The total phosphorus content is nearly always low in mor, when calculated on the basis of ignition loss (humus content) or volume. (Phosphorus by dry weight may be higher than in many mulls.) Nevertheless, the phosphate soluble in Egnér's lactate extractant is not appreciably lower than in mulls. Mors, and still more mulls, are very variable in the latter respect. As a broad average, about 10 % of the total phosphorus in mors is extracted by the lactate buffer, whereas less, and frequently much less, on this percentage basis, is extracted from mulls. Again, the Kroppefjäll *Calluna* heath samples behave as mulls.

Mull

The values for forest mulls are given in Table 2 and those for grassland and similar sites in Table 3.

The lower limit for total nitrogen in mull seems to be 2.4 % of the content of organic matter (as ignition loss), a value that is not frequently exceeded in mor in Sweden. It corresponds to a C/N quotient of about 20. The majority of mulls contain over 3 % and a few even 4 % or more, i.e. C/N about 16 and 12, respectively.

As mentioned above, total phosphorus is usually appreciably higher in mulls than in mors, but lactate soluble phosphorus is not generally so. Only a few among the most P-rich samples showed higher lactate soluble P than the mors, notably those from southern rich hardwood forests and the samples from dry meadow on the Archaean limestone occurring on the island of Runmarö E. of Stockholm. The lactate soluble P in mulls is nearly always less than 10 % of the total (the single exception, No. 188, is transitional to mor), and frequently much less, even less than 1 % in five cases (Nos. 149, 143, 6, 7 and 178). The two methods thus give quite disparate ideas about the P state of humus.

Mulls may be quite acid, as is well known. In the present material, how-

ever, only few pH values below 5 are met with. The percentage of »neutralization» ranges from 35 to 100 % in the present material (one value at 33 % in Sjörs 1954 p. 120). There is among the mulls only one case of probable »over-neutralization», i.e. with a surplus of metal ions in relation to soil acidoids and acids other than carbonic. Whether this mull (No. 193) actually contains $CaCO_3$ is uncertain, for on one hand high Ca^{2+} values were found, on the other hand pH was not high enough for a true carbonate soil. Both in this case and in a few others (Nos. 135, 207, 179, 138, 195, 126) there is a possibility that scattered grains of $CaCO_3$ may have been introduced into the humus horizon, for instance by animals such as earthworms or digging insects. In these cases a calcareous subsoil occurs below the humus layer sampled, which is not calcareous in a strict sense.

Such »impurities» of $CaCO_3$ also will affect the values for total extractable cations, so the »exchange capacity» will be high. It seems certain, however, that the true capacity for exchanging cations may occasionally amount to about 200 m.eq. per 100 g of humus in some mulls, and nearly always exceeds 100 m.eq., the lowest value being found in a mull transitional towards mor (No. 188).

The majority of the values for total extractable metal ions and for Ca^{2+} are much higher in mulls than in mors, as expected from the higher percentages of »neutralization» combined with the higher exchange capacities. Nevertheless there are a few cases recorded where Ca^{2+} is remarkably low in mull, as was also the case in some of the material presented in Sjörs 1954 (Table 13 p. 120).

Although there is on the whole a marked difference between mulls and mors in N, P, acidity, exchange capacity, total metal ions, and Ca^{2+}, some overlapping occurs in all these respects.

The values for K^+ are not consistently higher in mulls than in mors. The southern rich forest mulls are fairly rich in potassium, as well as in phosphorus (cp. above).

Grassland mulls do not differ significantly from forest mulls in any of the chemical properties investigated.

Peat

Since the present investigation was started, important progress in peat chemistry has occurred through numerous investigations, e.g. by Ramaut (1954, 1955 a and b, Deuse, Ramaut & Streel 1957) in Belgium, by Anschütz & Gessner (1954) in Germany, by Gorham (1953 b and c, 1956, 1957, 1958, in prep.), Newbould & Gorham (1956), Newbould (1960), Mitchell (1954), Gore & Allen (1956), Goodman & Perkins (1959), and others in Great Britain, by Malmström (1952), Gorham (1952), Mattson & Koutler-Andersson

(1954, 1955), Koutler-Andersson (1960), Malmer & Sjörs (1955) and Malmer (1958, 1960) in Sweden, and by the Finnish team cited in the introduction (Puustjärvi, Kaila, and others).

A great variety of chemical determinations has been tested, and workers in this field are far from agreement on a proper overall procedure. The sensitivity of the ion exchange complex in peats to various chemical treatments has proved to be greater and more complicated than could be expected when Brown's simple method was chosen for the present investigation. However, this method hardly yields results that are inferior to other types of determinations of the exchange complex. A decided advantage is that it involves only a weak chemical treatment of the samples, particularly when applied to fresh peat. The pH displacement due to metal cations is measured at a much lower pH than is the displacement due to hydrogen ions. This may be a serious drawback if the total cation exchange capacity proves to be more pH-sensitive than can be suspected from present data.

Two methods were used by Puustjärvi (1956 p. 412) to determine cation exchange capacity:

»1. The peat sample has first been shaken in 0.5 N hydrochloric acid in order to remove the basic cations, washed with distilled water until free of chlorides, shaken in 0.5 N barium acetate solution[1] and filtered; the filtrate was then titrated electrometrically with 0.1 N NaOH to pH 7.»

»2. The peat sample has been electrodialyzed and the exchange capacity has been determined in a 0.5 N barium acetate solution as before.»

Method 1 involves a treatment with strong acid (at pH about 0.3) that may cause considerable change of the organic acidoids. Method 2 is less objectionable (although time-consuming). Neither of the two methods give results that are strictly comparable to the values obtained in the present investigation, but it seems likely that those of method 2 are more comparable.

For dry peats, Puustjärvi found consistently higher results with method 1 than with method 2, except for humified *Sphagnum* peat where method 1 yielded much lower values. Puustjärvi assumed this to be an effect of the high content of hemicellulose in *Sphagnum* peat, giving rise during decomposition to polyuronides, which may act as part of the exchange complex. The most simple explanation of the lower results with HCl treatment seems to be that these polyuronides — or any type of acidoids characteristic of humified *Sphagnum* peat — are destroyed by strong acid. In other peats — formed from wood, sedges, *Bryales* and to some extent undecomposed *Sphagnum* — this effect would be more or less absent, but other processes may often be present which on the contrary tend to create more acidoids with strong acid. The mixed origin of most peats make this evaluation

[1] pH 7.0.

exceeding difficult. It also seems to apply chiefly to dried peats, whereas fresh peats may behave in a somewhat different way (pp. 438—445).

In the present material, which is shown in Table 4 and partly in Fig. 7 (p. 42), there is no case of a high cation exchange capacity in *Sphagnum* peat; this quantity, at least as determined with the present method, is of the same low magnitude as in mor. Gorham (1953 c p. 350), using the same method, found 51—129 m.eq. per 100 g ash-free peat. The present material consists only of surface peats which were mostly practically undecomposed, whereas the mors were generally much more humified. The »rich fen» peats seem frequently to have a somewhat higher exchange capacity than the other peats. One sample (No. 140, from a terrestrial rich fen with a meadow-like vegetation) was even comparable to a mull in this respect. Four of the samples proved to be »over-saturated»; they were all from peats developed above lime deposits (calcareous tufa or fen marl), and Nos. 146 and 152 at least contained visible lime contamination in spite of great care in sampling. In such cases, more Ca^{2+} than the exchangeable ions are included in the analysis, and the figure for metal cations is greater than the actual cation exchange capacity, which could not be computed from the present analyses.

The samples cover the entire acidity range from pine bog to calcareous »extremely rich fen» (Du Rietz 1949; see also e.g. Sjörs 1948, 1952). The percentage of »neutralization» is 16 or less in the true bogs (ombrotrophic bogs: Du Rietz 1954 b p. 574). It is considerably higher in the acid or poor fens (18—55); the few examples are not very representative ones. In samples from »moderately rich fen» (Du Rietz 1954 a p. 182; »transitional rich fen» in Du Rietz 1949), a percentage of »neutralization» of 47—77 was found. The »extremely rich fens» are all nearly completely neutralized or even »over-neutralized» (see above). The exchangeable H^+ ions are of course inversely related to the percentage of »neutralization».

The extractable metal ions (excess over anions) are clearly related to the vegetational sequence: 14 m.eq. or less in 100 g of combustible matter in ombrotrophic bog, 15—49 in poor fen, 45—80 in moderately rich fen, 93 or more in extremely rich fen. More overlapping may be expected in a larger series of observations. Thus Malmer gives slightly higher values from moderately poor fen (Site III: Malmer & Sjörs 1955 p. 69). The large amount of material in Puustjärvi (1957) could not be considered because the type of vegetation was not given. Higher values for ombrotrophic peat are often met with in oceanic regions (Gorham 1949, 1953 b and c, Boatman 1957; Gorham & Sjörs, not yet published data from Ireland). This is due to Mg^{2+}, not to Ca^{2+}. However, the sums of the metal ions determined by Gore & Allen (1956) in a bog in the northern Pennines are not higher than the Swedish ones.

Extractable Ca^{2+} is closely related to the above-mentioned vegetation sequence. In ombrotrophic sites, extractable Ca^{2+} amounts to 13 m.eq. or less in 100 g of combustible matter; in poor fen to 14—41 m.eq.; in moderately rich fen to 35—64 m.eq.; in extremely rich fen to 69 m.eq. or more, frequently much more. Again, more overlapping may be expected in data from a wider range of sites. Thus Puustjärvi (1956) gives several lower values from undoubted rich fen in Finland, and Malmer found only about 8 m.eq. Ca^{2+} in the poor fen site II, lawn (Malmer & Sjörs l.c.). Osvald (1937 p. 220, from Hjertstedt) also gave examples of low Ca contents in fen peats.

In three surface peats (Nos. 205, 204, 203) from the Roshult bog in Halland (described in detail by Olausson 1957), the sum of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} is much larger than the excess of metal ions over anions (as determined with acetic acid). The same, although to a weaker extent, is probably true of the other ombrotrophic peats, and two of the most acid poor fen peats as well. This may show either that considerable amounts of soluble anions of acids as strong as, or stronger than acetic acid are present as free or released, or that the rise in pH of acetic acid upon addition of peat is less than expected from the amount of dissolved metal ions for some other reason.

The amounts of extractable Ca^{2+} and Mg^{2+} as well as their ratio is of the same magnitude in the Roshult bog as in the surface peat of the Ramna bog investigated by Mattson & Koutler-Andersson (1954 p. 331). Both bogs are situated only about 20 km from the sea, but the Roshult bog is in a region of still higher precipation (Olausson, op.c., O. Tamm 1959 pp. 9—10).

Ca^{2+} usually constitutes the majority of the metal ions, with the exception of more or less oceanic bogs (Mattson, Sandberg & Terning 1944). The Ca/Mg ratio is less than 1 in the Roshult bog but much greater than 1 in the inland bog Bredmossen.

The ash content of the surface peat is very high for ombrotrophic conditions (5.3 %) in the Ramna bog, which is affected by draining, and surrounded by a high percentage of arable land particularly to the west. The Roshult bog, which is entirely undrained, is largely surrounded by other mires, heaths that were formerly heavily burnt, and woodland. Also the Roshult bog is rich in ash near its surface (over 7 % according to Olausson 1957 p. 37; 3.7, 3.7 and 6.6 % in my samples). About 3 % of ash was found in the inland bog Bredmossen, ca. 300 km from the Skager Rak and 85 km from the Baltic. Only 1.3, 1.8 and 2.5 % were found in the inland bog Tisjökölen (ca. 220 km from the Skager Rak and ca. 240 km from the Baltic). This bog is situated in a completely uncultivated district. Ash values as low as about 1—2 % occur regularly at 0.4 m and more below the surface even

in the Ramna and Roshult bogs. The high values in the top layer cannot be solely an effect of the nutrient uptake of the plant cover, but are believed to be caused by an increase in atmospheric deposition as a result of industrial and agricultural activity. »Mineral matter from wind erosion must have assumed much greater proportions with the development of agriculture» (Mattson & Koutler-Andersson 1954 p. 363, 1955 p. 223).

Potassium is frequently slightly lower in the bogs than in the fens. It is likely that some of the K^+ found is actually held in rootlets, mycorrhizae, mycelia, and other living matter, and the content of living material will influence the K^+ values found. The potassium standard of the peat humus itself may thus be still lower. It is known to decrease considerably downward in the peat profile (Kaila & Kivekäs 1956 pp. 244—245).

Malmer (1958 p. 283; see also Malmer & Sjörs 1955 p. 75) concludes that a very large part of the total K involved in the biogeochemical cycle is actually present in the living part of the ecosystem. The potassium conditions in fens and bogs thus resemble those assumed for rainforests growing on laterite soils extremely poor in nutrients.

Malmer's figures for K^+ in peat (1958 Fig. 2 p. 278) are generally lower than the present ones, particularly with reference to fens, which in his material seem to be nearly as poor in K^+ as the bogs.

There is not very much more potassium stored in terrestrial humus than in peat. Terrestrial humus soils and fens differ from bogs in the presence of a continuous addition of K^+ derived directly or indirectly (via the plants) from weathering of minerals, or from mineral soil water seepage, but nevertheless, the potassium held in living organisms may be an essential part of the available total also in these ecosystems, even if only in certain cases as essential as in bogs (cp. Malmer 1960 p. 111).

Phosphorus conditions in peat resemble those in mor, but still lower values are found particularly for total P. The next lowest sample in this respect, No. 142, from moderately rich fen, shows the highest lactate-soluble fraction (34 %). The four samples 5, 14, 15 and 137, also from rich fen, deviate from the other peats in having a very small lactate-soluble fraction (0.6, 0.5, 2.0 and 1.7 %). The »lactate P» values thus are extremely low in these samples in spite of total P values rather high for peat; this relation is reminiscent of mull although the P standard is lower than in most mulls.

Kaila (1956 b and c, 1958, Kaila & al. 1957) has studied the phosphorus content of peats in Finland very extensively. He has shown that about ⅔ or usually more of the total P is present as organic compounds in surface peat, and still more in deeper layers. The inorganic P, in turn, is only moderately soluble in water or various more or less acid and ion-exchanging extractants; the solubility varies rather irregularly with the extractant. Unfor-

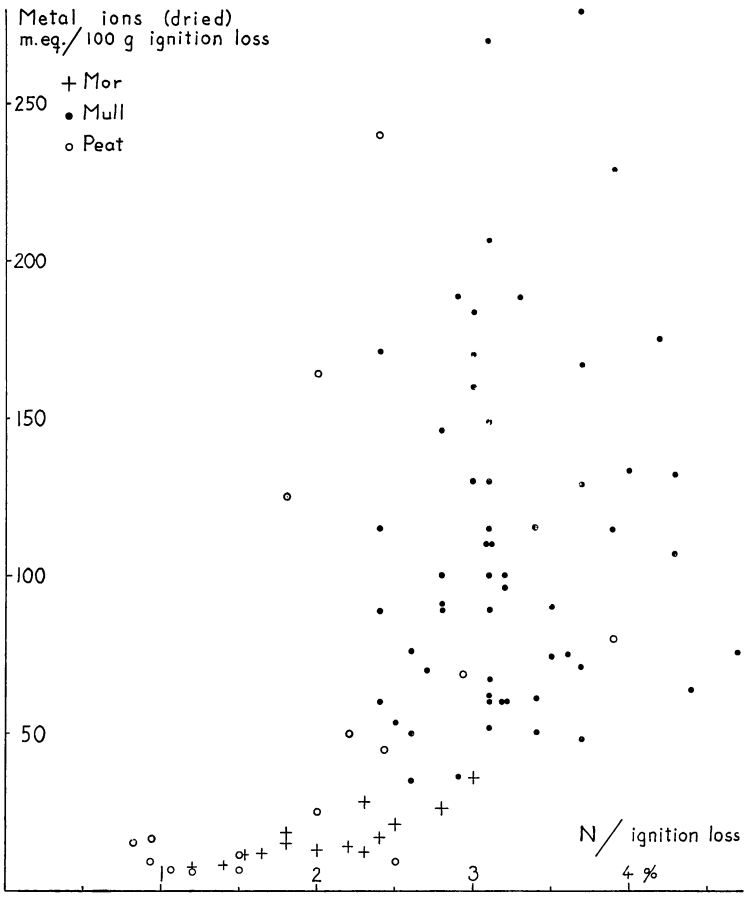

Fig. 3. Extractable metal ions, determined by acetic acid pH displacement with dried samples, in relation to Kjeldahl nitrogen, both on ignition loss basis. Values from Sjörs 1954 (Table 13; grassland mulls) included.

tunately, he has not tested Egnér's lactate extraction, so the figures obtained with this metod are not comparable with his results. The present values for total P are of the same magnitude as Kaila's, except in the present samples 14, 137 and 152, in which total P is obviously exceptionally high for peats, and higher than in all surface peats investigated by Kaila.

The total nitrogen content of peat is variable. On the whole, bog peats and some poor fen peats are poorer in N than the rest, but parent material, degree and type of humification (Malmström 1952 p. 23) and also local conditions effect the N percentage so considerably that relations to the mire vegetation types are obscured. Even in such narrowly circumscribed vegetation types as each of the five kinds of treeless *Sphagnum papillosum* mires

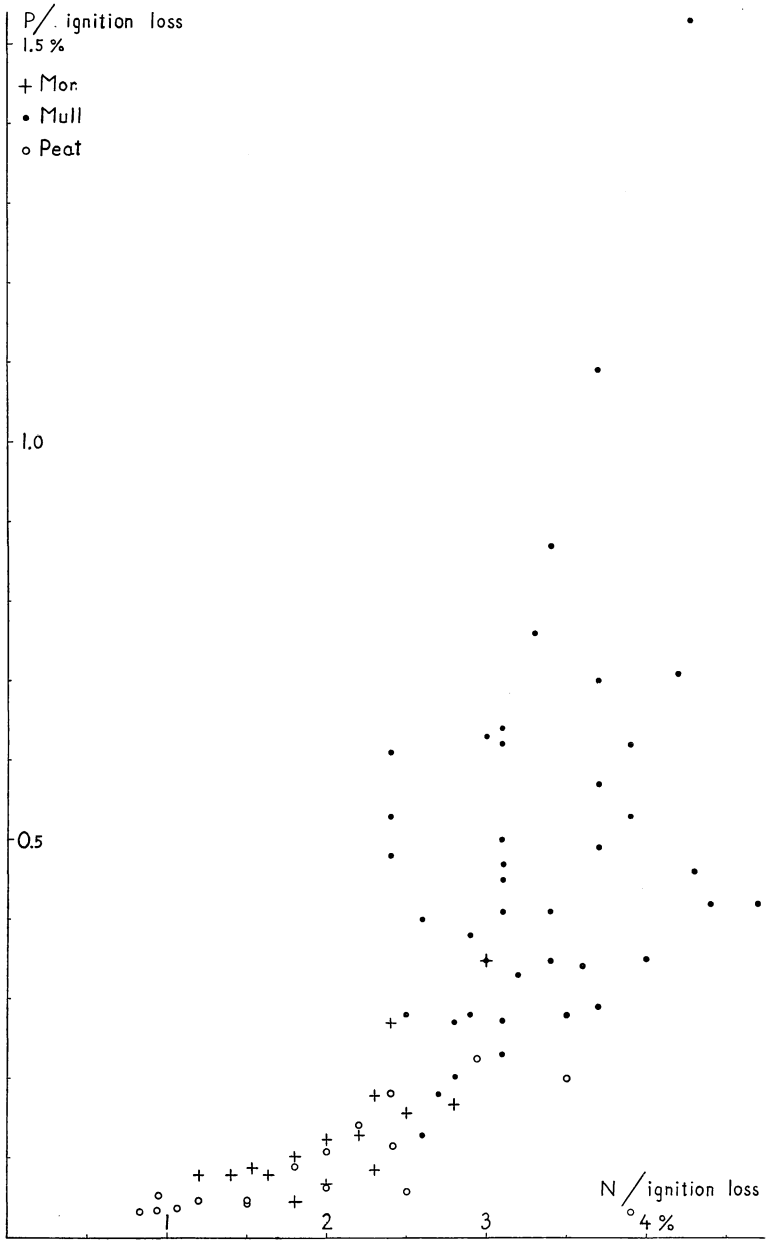

Fig. 4. Total phosphorus in relation to Kjeldahl nitrogen, both on ignition loss basis.

studied by means of five or more samples in the investigation by Kaila & al. (1957), the variation is very large in N, as well as in other chemical respects. A large variability even within the individual peat groups is also evident for instance in the great number of N determinations listed in Kaila 1956 c. According to him *Sphagnum* peat is considerably and significantly lower in N than other peats, in a few cases even below 1 % (two cases in poor fen and one in bog in the present material). Gorham (1953 c, Fig. 1, p. 351) shows three such cases, and emphasizes the low N content of living *Sphagnum* (p. 359). In Swedish bog-peats N may be as low as 0.5 % (Koutler-Andersson 1960). On the whole, a high content of remains of bryophytes or of wood tends to lower the total N percentage.

On a large number of samples Puustjärvi (1956 p. 434) was unable to find a correlation between the N content and the cation exchange capacity of peat. If such a correlation exists, it would according to him be slightly negative. Malmström (1952), however, found more N in the well-decomposed peats, which contain more colloid matter. In the present material very low values for N are never combined with high values for metal ions, nor for total cations. Otherwise no correlation exists in peat, but probably a positive correlation occurs in mor (Fig. 3). Similar conditions occur regarding total P in relation to cations. Therefore a certain correlation may be expected between P and N (see Fig. 4).

A strong negative correlation was found between total nitrogen and excess base (in ash) by Mattson & Koutler-Andersson (1954 p. 348; 1955) and by Koutler-Andersson (1960), when comparing samples from vertical series in ombrotrophic bog profiles. These authors state that this feature is not present in fens, or when comparing peat types from different sites. If figures for N and »excess base» in surface peat (12 bogs) in Koutler-Andersson 1960 are compared with each other, only a very uncertain negative correlation is found, so it seems that this nitrogen-base relation is a feature in the development and succession within the individual bog rather than a general feature when bogs are compared with each other.

In comparing the present results with those of other investigations it should be observed that the present values are computed on the ash-free basis, and on the natural volume basis, which was not the case in the Finnish investigation cited, where the volume was measured on ground dried samples.

Comparative conclusions

In the analytical material presented, to which in a few cases the values in Sjörs 1954 have been added, various pairs of properties could be selected for coordinate plotting. Interdependent properties have not been plotted, as for instance Ca^{2+} ions versus total cations, or exchangeable H^+ ions versus »percentage of neutralization». Also diagrams showing no correlation at all have been omitted.

It has been avoided to plot chemical properties which have already been calculated on the ignition loss basis, against loss on ignition (humus content). The latter shows low values much more frequently in mull than in mor and peat. Such diagrams would therefore give the impression that the chemical properties of humus were related to the content of humus whereas in reality they are more consistently related to the quality or type of the humus layer. Some of this impression would remain, even with the different symbols used in the diagrams. Compare, however, Gorham 1953 a (Figs. 4—9, pp. 133—136).

The published diagrams are of three kinds. The first is represented by Fig. 1 (p. 12), for pH, and by Fig. 2 (p. 15), for total metal ions. Both are purely methodical comparisons between dried and fresh samples. The second kind of diagram involves the plotting of two independent variables which show a weak correlation because they both reflect the general condition of the humus. Here belong the relation of extractable metal ions to nitrogen (Fig. 3, p. 25), and the relation of phosphorus to nitrogen (Fig. 4, p. 26), which have been mentioned above. Such diagrams show above all the range of variation in each property in relation to type of humus, but hardly much more. The next two diagrams (Fig. 5, p. 29, and Fig. 6, p. 30) show pairs of properties that are independently determined but manifestly correlated both numerically and logically.

Fig. 5 shows the relation of the »degree of neutralization» to pH. The diagram had to be made from determinations on dried samples, too few values from fresh soils being available. The regression line for dried samples is shown to be slightly sigmoid. Similar diagrams have been published by Gorham (1953 a p. 137, 1953 c p. 355). Gorham's diagrams, particularly the former, show predominantly lower pH values, especially in the acid range, which is doubtless due to a different pH technique (direct insertion of the glass electrode in the nature-moist soil).

Fig. 6 shows volume weight in relation to ignition loss. The correlation is obvious but the regression line is curved. At both ends the correlation becomes weaker. At high values of ignition loss, such as occur in pure peat and mor with little contamination of mineral grains, the variable content

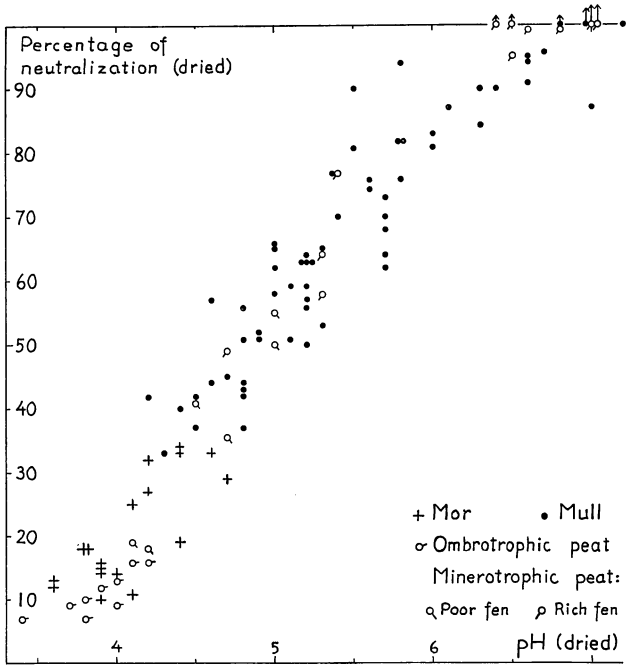

Fig. 5. Percentage of neutralization (metal ion saturation, in excess over anions), in relation to water extract pH. The arrows indicate »over-neutralization». Dried samples. Values from Sjörs 1954 (Table 13; grassland mulls) included.

of true ash influences volume weight only slightly. The latter is then chiefly related to the porosity, determined by packing and structural properties. On the other hand, when the humus content is small, the volume weight is mainly determined by the composition, texture and packing of the mineral component. But in the middle range of variation the humus content becomes the chief factor determining volume weight, although there is a considerable scattering which is above all due to variation in porosity, i.e. chiefly the effect of structure and packing. A similar diagram is given by Gorham (1953 a p. 130). His humus-rich mors are somewhat heavier, i.e. less porous.

From volume weight and percentage organic matter, the porosity may be roughly estimated. According to the present material, the average porosity of Swedish humus soils rises considerably with the humus content. If we assume a specific gravity of 2.7 for the mineral component and slightly over 1 for the humus material, the porosity would be about 65—70 % at 10 %, 75 % at 20 %, 80 % at 35 %, 85 % at 60 %, 90—95 % at 80 % and higher ignition loss. In undecomposed *Sphagnum* peat the porosity may occasionally be as high as 97 %. The porosity of mors may exceed 90 %; in mull a porosity about 85 % is not exceptional.

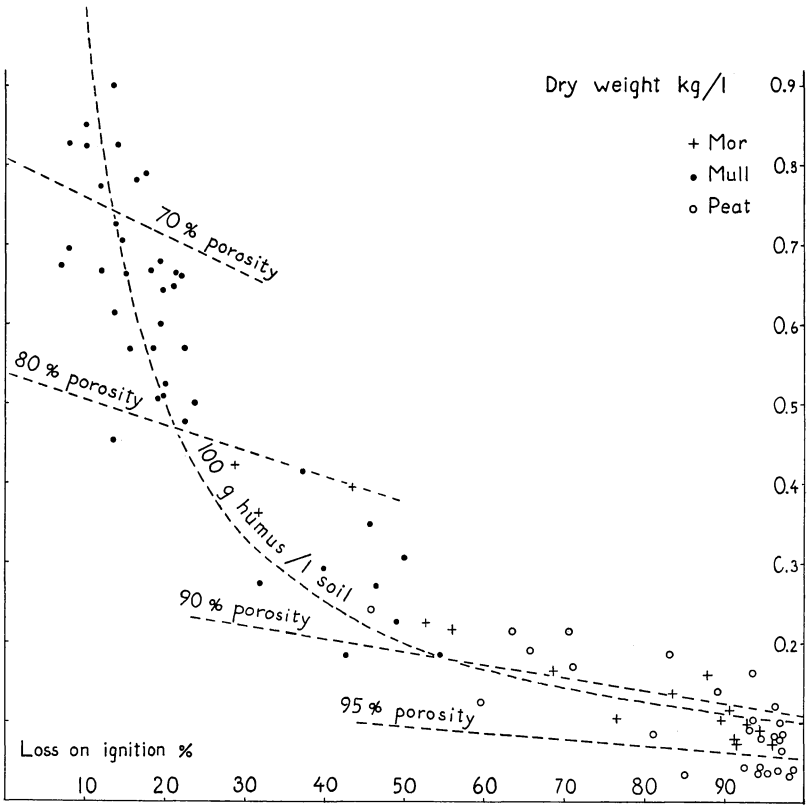

Fig. 6. Volume weight of air-dry soil in relation to loss on ignition. Lines indicating approximate porosity have been inserted, as well as a curve showing position of samples containing 100 g humus per litre. Three values from Sjörs 1954 (Table 13; grassland mulls) included.

The content of humus per unit volume, which can easily be calculated from the Tables or from the values in Fig. 6, is variable, but the mean value does not differ much in various kinds of humus layer, being about 100 g per l in mulls with about 12—20 % ignition loss and also in many more or less pure mors. Romell (1932 p. 165) stated similar values. In soils of medium humus percentage by weight, the humus content by volume is normally somewhat higher (120 to 130 g per l). Occasionally the humus content may be as high as about 150 g per l. Owing to high porosity it may, on the other hand, be as low as about 35 g per l in certain peats. If the humus percentage by weight is very low (less than 10 % ignition loss), the content by volume is of course also low, but only exceptionally less than 50 g per l in soils that still can be regarded as »humus layer».

These considerations, regarding both porosity and humus content by volume, apply of course only to the top layer that has been sampled.

Notes on sampling sites

Some of the sites have been characterized by vegetation analysis and examination of the soil profile, whereas for others only short field notes have been taken. The inequality of the notes makes it impossible to give a full treatment with, for instance, full species lists or vegetation tables. Also consideration of space makes it necessary to reduce the material to a few concise statements. Only the general nature of the vegetation and soil is given. Total omission of such data in a paper on humus chemistry would reduce its value for ecological purpose considerably.

Mors

Table 1 p. 44.

130. Jämtland, Åre, Högåsen N. of Enafors, upper subalpine region, treeless wet mountain moor similar to a bog, but humus layer too shallow to be strictly ombrotrophic. Hummock with *Loiseleuria procumbens, Empetrum hermaphroditum, Cetraria nivalis;* 19 cm of mor on bleached fine sand.

183. Skåne, »Skanörs ljung» on the Falsterbo peninsula between Öresund and the Baltic, northern part, *Calluna* and *Erica tetralix* moor with deep sandy mor on quartz sand.

198. South of preceding, in the middle of the open moor.

197. Near south shore, but still on the moor. Sandy mor.

202. Halland, Tönnersjö, 1.2 km W. of Esmared. *Calluna vulgaris, Vaccinium vitis-idaea, Pleurozium Schreberi,* scattered pine, birch and *Molinia.* 7 cm of mor on 8 cm dark A_1.

206. Halland, Veinge, 1 km W.N.W. of Mästocka. Treeless heath. Almost pure *Calluna* with *Pleurozium.* 3—4 cm of mor, lower part sandy.

190. Skåne, Långaröd or Fränninge, N.E. of Vallarum. *Calluna,* some *Vaccinium vitis-idaea, Pleurozium.*

177. Dalsland, Ödeborg, steep S. edge of the hills »Kroppefjäll» N.E. of Ödegård. *Calluna* heath with *Deschampsia flexuosa, Pleurozium, Cladonia rangiferina* and *silvatica* (agg.), few additional species (e.g. *Carex digitata, Silene rupestris).* Thin mor on gneiss rock.

176. Dalsland, Sundals-Ryr, Sjöbotten, 2 km N.E. of preceding, similar but with richer additional flora, e.g. *Potentilla erecta, Ajuga pyramidalis, Fragaria vesca.*

171. Dalarna, Lima, Tisjölandet. Pine lichen forest: *Calluna, Vaccinium vitis-idaea, Cladonia silvatica* (agg.) and *rangiferina, Pleurozium, Cetraria islandica.* Thin mor on sandy glacial till. Podsol.

145. Ångermanland, Ramsele. Pine forest with *Vaccinium vitis-idaea, Calluna, Empetrum hermaphroditum, Maianthemum bifolium, Pleurozium, Dicranum polysetum (= D. undulatum), D. scoparium, Cladonia rangiferina.* Thin mor on sand. Podsol.

13. Västmanland, Västerfärnebo, Hedåker. Pine lichen forest with *Calluna, Vaccinium vitis-idaea, Arctostaphylos uva-ursi, Cladonia rangiferina, silvatica* (agg.) and *alpestris, Cetraria islandica, Dicranum polysetum.* Thin mor on gravel on top of an esker.

184. Skåne, Örkened, Nyteboda. Tall spruce forest, wet part with *Polytrichum*

commune, Sphagnum Girgensohnii and *parvifolium,* some *Vaccinium myrtillus* and *vitis-idaea,* more than 10 cm of mor on glacial till.

185. Same locality, not wet. *Hylocomium splendens, Dicranum majus,* some *Rhytidiadelphus loreus, Bazzania trilobata* and *Polytrichum formosum.* No field layer. Mor on till rich in boulders.

2. Dalarna, Garpenberg, between Bengtsbo and Getmossen. Spruce forest, typical *Vaccinium myrtillus* undergrowth (with *Deschampsia flexuosa, Melampyrum pratense, Pleurozium, Hylocomium splendens, Dicranum majus,* see also Samuelsson 1960 p. 83 and Table IV nos. 1—2). Mor on podsolized till.

150. Jämtland, Hammerdal, Fyrås. Spruce forest with *Vaccinium myrtillus, Linnaea borealis, Deschampsia flexuosa, Hylocomium splendens, Barbilophozia lycopodioides, Ptilium crista-castrensis.* 6 cm of mor on podsolized till (probably originally calcareous but leached free of carbonate).

164. Dalarna, Lima, S. shore of Lake Tisjön, small hill with *Betula pubescens* wood; scattered spruce, much *Vaccinium myrtillus* and *Hylocomium splendens,* deep mor on coarse till, podsolized.

182. Skåne. Söderåsen at Skäralid (near Kopparhatten), beech forest of »heath» type, lacking undergrowth. 4 cm of mor below much leaf litter, on sandy till which is only slightly podsolized (this is south of the region of regular podsolization in S.W. Sweden).

201. Halland, Breared, Skällsås. *Quercus petraea* (hybrids?), some *Betula verrucosa,* spruce and beech, *Rhamnus frangula, Vaccinium myrtillus* and *vitis-idaea, Deschampsia flexuosa.* About 4 cm of mor on sandy gravel, distinctly podsolized but A_1 rather thin and irregular.

186. Skåne, Vånga, Dyneboda. *Quercus petraea* and hybrids, *Vaccinium myrtillus, Deschampsia flexuosa,* scattered *Calluna* and patches of *Hylocomium splendens* and *Pleurozium.* Much oak litter, F layer mor-like, H layer more mull-like, sandy, with some earth-worms. Signs of activity of moles. Mineral soil sandy, slightly podsolized.

Forest mulls

Table 2 p. 46. Mostly with earth-worms.

4. Dalarna, Garpenberg, Bengtsbo. Spruce forest with *Vaccinium myrtillus* and numerous low herbs (e.g. *Rubus saxatilis, Oxalis acetosella, Anemone hepatica* and *nemorosa, Viola riviniana*); bottom layer with *Hylocomium splendens, Pleurozium, Dicranum majus, Mnium affine, Rhodobryum roseum, Cirriphyllum piliferum.* 5 cm of sandy mull on thin humous sand on top of till; brown earth profile; the site is rather moist in wet seasons but hardly flushed. Forest developed from wooded pasture (Samuelsson 1960 p. 86; compare his Table V nos. 5—8).

6. Dalarna, Garpenberg, Fransbo. Spruce forest with pine and hardwoods, e.g. young *Fraxinus excelsior, Alnus incana, Viburnum opulus.* Rich under-vegetation (33 species in field layer, 12 bryophytes, e.g. *Melica nutans, Deschampsia caespitosa* and other grasses, *Carex vaginata, pallescens* and *digitata, Filipendula ulmaria, Cirsium heterophyllum, Anemone hepatica* and *nemorosa, Plagiochila asplenioides, Cirriphyllum piliferum, Sphagnum warnstorfianum.* Deep mull with well-developed F and H layers, on sandy mineral soil; brown earth profile; site seasonally flushed. Forest developed from mown meadow (probably park-meadow) via wooded pasture (Samuelsson 1960 p. 90—91 and Table VIII no. 2).

173. Dalarna, Lima, Bodarna (near Lake Tisjön). Below *Sorbus aucuparia* on otherwise open hay-meadow (see grassland mull, no. 172). *Geranium silvaticum, Alchemilla* spp., *Deschampsia caespitosa, Agrostis tenuis;* few mosses *(Hylocomium pyrenaicum, Rhytidiadelphus squarrosus, Rhodobryum roseum* noted). Sandy mull.

141. Jämtland, Frostviken, between Lakes Jormvattnet and Blåsjön, subalpine region at about 700 m, medium snow cover, flushed. *Betula pubescens* ssp. *tortuosa* scattered, with scrub of the same, *B. nana, Salix lapponum* and *Juniperus communis*. Field layer codominants: *Vaccinium myrtillus, Geranium silvaticum, Trollius europaeus, Empetrum hermaphroditum, Deschampsia flexuosa* and *Viola biflora;* numerous other species, e.g. *Anemone nemorosa, Saussurea alpina, Coeloglossum viride, Gnaphalium norvegicum, Bartsia alpina, Thalictrum alpinum, Polygonum viviparum;* among mosses e.g. *Hylocomium pyrenaicum*. Well humified dark sandy humus (no mull structure, as earth-worms are lacking at this altitude) gradually passing into humous sandy till chiefly formed from schist.

154. Jämtland, Hammerdal, Fyrås. Mixed forest (mainly spruce and *Betula pubescens)* with *Vaccinium vitis-idaea, Lastrea dryopteris, Rubus saxatilis, Equisetum scirpoides,* some *Aconitum septentrionale;* moss chiefly *Hylocomium splendens*. Dark humus containing black carbonized fossil organic matter from the alum shales, no. 153. Therefore, only part of the ignition loss represents recent humus.

153. Subsoil of preceding. Weathered alum shales near a brook; almost black, with fine texture but containing fragments of the shales; the latter with an ignition loss of 11 %.

136. Steep edge of the alum shales between Fyrås and Ånge. Mixed spruce and birch; grazed lush field layer: *Filipendula ulmaria, Geranium silvaticum, Stellaria nemorum* ssp. *montana, Tussilago farfara, Deschampsia caespitosa* etc.; an outpost locality for *Carex atrata*. 9 cm of typical mull on 8 cm of less typical, passing into humous mineral soil (B horizon), hardly podsolized and well flushed by fairly calcareous water.

149. Near preceding, less flushed, and not grazed at present. Dense, medium tall *Aconitum septentrionale,* sub-dominant very tall *Milium effusum* (235 cm), numerous other species. 7 cm of typical mull on 12—17 cm of less typical, passing into humous gravelly soil. No podsolization.

135. Below preceding, strongly flushed, close to a well. Very dense and tall *Aconitum* (230 cm, in late summer even 260 cm), *Urtica dioeca* (180 cm), *Filipendula ulmaria, Stellaria nemorum* ssp. *montana, Heracleum sphondylium* ssp. *sibiricum* (Sjörs 1956 Fig. 85 p. 159). Dark wet mull between boulders, with decreasing humus content extending down to at least 40 cm, water-logged below 20 cm; no podsolization or other sign of weathering. The water is calcareous. — Further data on the Fyrås localities in Sjörs 1950 (p. 28).

143. Jämtland, Frostviken, Jormlien. Montane spruce-forest, grazed; opening with *Aconitum, Geranium silvaticum, Stellaria nemorum* ssp. *montana, Crepis paludosa, Ranunculus platanifolius, Lactuca alpina, Polygonatum verticillatum, Milium,* etc. Deep mull containing earth-worms (rarely found in montane sites).

188. Skåne, Vånga, Brotorpet. Beech forest with some aspen; *Anemone nemorosa, Deschampsia flexuosa, Luzula pilosa, Dicranum scoparium, Hypnum cupressiforme; Hedera* grows near-by, but moister. Mull transitional to mor.

200. Halland, »Frodeparken», near Slättåkra. Thinned beech, with *Deschampsia flexuosa, Anemone nemorosa, Oxalis acetosella.* 15—20 cm of poor mull; deep brown earth profile.

181. Skåne, Tolånga, Anklam. Beech forest with *Galium odoratum, Maianthemum bifolium, Oxalis acetosella, Viola reichenbachiana, Polytrichum formosum.* Sandy mull.

180. Skåne, Högestad, Lyckås. Beech forest with richer flora than the preceding, e.g. *Lamium galeobdolon* and (only scattered) *Mercurialis perennis.* Sandy mull.

189. Skåne, Degeberga, Forsakar. Beech forest with *Lamium galeobdolon, Oxalis acetosella,* etc. Gravelly mull. — N. B. The richest types of beech forest are not represented in the material.

1. Dalarna, Garpenberg, Hässlen. Dense hazel scrub (formerly park-meadow); field layer dominants *Maianthemum* and *Oxalis;* rich flora, e.g. *Anemone hepatica, Milium effusum, Viola mirabilis, Pulmonaria officinalis* ssp. *obscura* (northern outpost). Typical mull on till; brown earth profile. Compare Samuelsson 1960 p. 116.

7. Dalarna, Garpenberg, Realsbo hage. Thinned, young hardwood forest, no longer grazed (formerly a wooded pasture); with *Fraxinus, Betula pubescens, B. verrucosa* and *Alnus glutinosa (A. incana* and spruce being exterminated). Very rich in species (about 150 vascular plants and more than 30 bryophytes); at sampling site dominant *Carex vaginata, Anemone hepatica, Rubus saxatilis* and patches of *Rhytidiadelphus triquetrus.* About 10 cm of mull gradually passing into sand and fine sand (till partly covered by sediments). Part of locality seasonally flushed; brown earth profile.

191. Skåne, Dalby, Dalby hage (see Lindquist 1938 b). Sampling site near beech; *Anemone ranunculoides* and *nemorosa, Corydalis cava, Mercurialis perennis,* etc. Deep typical mull gradually passing into clayey till.

207. Same near *Ulmus glabra,* the same field layer plants plus *Ranunculus ficaria.*

179. Skåne, Benestad, Örup. *Ulmus glabra* forest, under-vegetation as preceding, but pure *Mercurialis* at sampling site. Deep, typical but slightly stony mull, subsoil probably calcareous.

208. Skåne, Hardeberga, Fågelsång. Between *Quercus robur, Tilia cordata, Prunus padus,* etc.; field layer *Anemone ranunculoides* and *nemorosa, Mercurialis, Ranunculus ficaria, Corydalis cava, Lamium galeobdolon, Gagea lutea,* etc. Deep, typical but gravelly mull.

193. Same but moister. *Petasites albus* dominant, with *Chrysosplenium alternifolium. Ranunculus ficaria,* etc. Deep, wet, somewhat sandy mull, subsoil probably calcareous.

8. Dalarna, Garpenberg, Hässlen. *Alnus incana* thicket with rich hygrophilous flora (see Samuelsson 1960 p. 107 and Table XI p. 111). Wet sandy to silty mull of poor structure on stony, silty subsoil (brook sediment). Not podsolized.

187. Skåne, Vånga, Kasseboda. *Alnus glutinosa* swamp, flushed, fairly rich vegetation with *Rubus idaeus, Oxalis acetosella,* etc. Wet mull, with sediments of sand incorporated. Non-calcareous.

192. Skåne, Dalby, Dalby hage, near brook. *Alnus glutinosa, Fraxinus excelsior, Ulmus glabra, Ranunculus ficaria, Urtica dioeca, Aegopodium podagraria, Chrysosplenium alternifolium, Filipendula ulmaria,* etc. Dark plastic wet mull, subsoil probably calcareous.

Grasslands mulls

Table 3 p. 48. Earth-worms were noted in nearly all cases.

194. Skåne, 1.5 km N.E. of Dalby, pasture with *Juniperus* and *Calluna*. Sample from grassy parts, with *Festuca ovina, Galium saxatile, Luzula campestris, Anemone nemorosa, Pseudoscleropodium purum,* etc. Sandy, poor mull, somewhat similar to mor in top part, on non-calcareous till. Brown earth profile slightly leached near surface.

134. Jämtland, Hammerdal, Fyrås. Mown grassland of poor type, with *Festuca ovina, Anthoxanthum odoratum, Deschampsia flexuosa,* much *Hylocomium splendens,* etc.; 4 cm S-layer (moss and litter). 9 cm of mull with poor structure, passing into clayey, stony till. Brown earth profile.

172. Dalarna, Lima, Bodarna near Lake Tisjön. Open grassland near sample 173 (Table 2, forest mull). *Agrostis tenuis, Deschampsia caespitosa, Veronica chamaedrys, Alchemilla* spp., *Rhytidiadelphus squarrosus,* etc. Sandy mull. Subsoil podsolized.

151. Jämtland, Hammerdal, Fyrås. Grazed dry meadow. *Deschampsia caespitosa, Polygonum viviparum, Trifolium repens, Anthoxanthum odoratum, Botrychium lunaria, multifidum* and *lanceolatum, Rhytidiadelphus squarrosus, Polytrichum juniperinum, Tortula ruralis,* etc. Very thin mull on fine-sandy till, slightly podsolized.

139. Between Fyrås and Ånge. Dry grassland with moderately rich flora. *Anthoxanthum, Nardus, Festuca ovina, Hypochoeris maculata,* a few *Gymnadenia conopsea, Rhytidiadelphus squarrosus,* etc. 5—8 cm of mull on gravelly soil, distinctly podsolized but A horizon incorporated into the mull.

148. Same locality, above no. 149 (Table 2, forest mull). Similar to the preceding: *Anthoxanthum, Agrostis tenuis, Deschampsia flexuosa, Arrhenatherum pubescens, Hypochoeris maculata, Rhytidiadelphus squarrosus,* etc. 15 cm of mull gradually passing into till (somewhat clayey); brown earth profile.

147. Near 139. The same three dominant grasses as in 148 but still richer in species (45 vascular plants, 11 mosses in 20 m^2), e.g. *Carex pallescens, C. digitata, Listera ovata, Selaginella selaginoides, Hypochoeris maculata, Parnassia palustris, Thalictrum alpinum, Briza media, Plantago media, Thuidium recognitum, Abietinella abietina, Hylocomium pyrenaicum.* Very deep rooting. 11 cm of mull very gradually passing into gravelly soil. Brown earth profile, with rust-coloured B horizon but no proper podsolization.

144. Fyrås. Dry meadow dominated by *Trifolium medium,* otherwise of the same vegetation type. Thin mull on gravelly till rich in shale, probably brown earth profile.

138. Near nos. 139 and 147, less dry, vegetation dominated by *Cirsium heterophyllum, Vicia silvatica, Agrostis tenuis, Hylocomium splendens* and *pyrenaicum.* Rich in other species, e.g. *Thalictrum alpinum, Hypochoeris maculata, Arrhenatherum pubescens, Potentilla Crantzii, Selaginella selaginoides.* Soil similar to no. 147.

129. Uppland, Djurö, Runmarö (40 km E. of Stockholm), near Lake Vitträsk. Dry meadow, with *Festuca ovina, Galium verum* and *boreale, Filipendula vulgaris, Centaurea jacea, Hypericum perforatum, Linum catharticum, Rhytidiadelphus squarrosus.* Mull on shallow soil resting on Archaean limestone. Cp. nos. 126—128 below.

209. Skåne, Köpinge, Mjö. Dry meadow; dominants *Festuca ovina, Arrhenatherum pratense, Camptothecium lutescens, Thuidium Philiberti;* among other species *Potentilla heptaphylla* and *Tabernaemontani, Ranunculus bulbosus, Thymus serpyllum, Polygala amarella.* Mull very deep, passing into mineral soil at about 45 cm, lower part with some $CaCO_3$; concretions of $CaCO_3$ at about 50 cm; also a rust-coloured horizon at about 60 cm; subsoil strongly calcareous (chalky) sand. Vegetation and soil profile recorded by S. Waldheim.

195. Öland, Vickleby, on the Alvar. Dry meadow, grazed, alvar type (cp. Albertson 1950 p. 304), with e.g. *Globularia vulgaris, Oxytropis campestris, Helianthemum oelandicum, Sedum rupestre, Viscaria alpina, Prunella grandiflora, Orchis mascula, ustulata* and *sambucina, Anthyllis vulneraria, Galium triandrum, Phleum phleoides, Arrhenatherum pratense, Anemone pratensis, Silene nutans, Polygala comosa, Filipendula vulgaris, Carex flacca, Rhytidium rugosum,* and many others. Shallow brown, powdery, sandy insect mull, on very low gravel ridge resting on flat limestone. Brown earth profile calcareous from 10 cm downward.

175. Dalsland, Sundals-Ryr, Sjöbotten (near no. 176, Table 1). *Geranium sanguineum* rock-meadow, with *Juniperus, Calluna, Agrostis canina* ssp. *montana, Melica nutans, Origanum vulgare, Hypericum perforatum, Sedum telephium,* etc. Shallow dark humus on rock (gneiss, partly schistose?).

178. Dalsland, Ödeborg, Ödegård, near no. 177 (Table 1), but similar to the preceding. In addition e.g. *Vicia cassubica.*

126. Uppland, Djurö, Runmarö, near Lake Vitträsk (cp. no. 129 above). *Sedum album, Bromus mollis, Draba muralis, Saxifraga tridactylites* and *granulata, Woodsia alpina, Abietinella abietina,* etc. About 4 cm of humus on Archaean limestone rock.

127. Same locality. *Festuca ovina* vegetation with *Arrhenatherum pubescens, Saxifraga granulata, Galium verum, Plantago lanceolata, Rhytidiadelphus squarrosus, Climacium dendroides.* About 10 cm of humus on the same rock, sample from upper part (1—4 cm).

128. Lower part of the preceding (6—10 cm, more sandy). — N.B. These three soils were very heterogeneous, as seen from the variable and inconsistent values for total metal ions and Ca^{2+}.

Peats

Table 4 p. 50.

165. Dalarna, Lima, Tisjökölen. Pine bog: *Vaccinium vitis-idaea, myrtillus* and *uliginosum, Betula nana, Pleurozium,* etc. Sample at about 10 cm.

166. Same but lacustrine (eroded bog shore); *Calluna* and *Pleurozium* dominants.

10. Dalarna, Avesta, Bredmossen (Sjörs 1948 p. 180). Marginal pinewood zone of the bog. *Betula nana, Ledum palustre, Rubus chamaemorus, Calluna vulgaris, Eriophorum vaginatum, Vaccinium uliginosum, vitis-idaea* and *myrtillus, Cladonia rangiferina* and *silvatica* (agg.), *Pleurozium, Dicranum Bergeri,* etc.

167. Tisjökölen, hummock; *Calluna, Empetrum* sp., *Rubus chamaemorus, Eriophorum vaginatum, Sphagnum fuscum, Pleurozium,* etc.

12. Bredmossen, hummock; *Calluna, Rubus chamaemorus, Cladonia rangiferina* and *silvatica* (agg.), *Sphagnum fuscum,* etc.

205. Halland, Tönnersjö, Roshultsmyren, hummock; *Empetrum nigrum, Sphagnum imbricatum,* etc. Cp. Olausson 1957.

168. Tisjökölen, hollow; *Trichophorum caespitosum, Sphagnum balticum,* etc.

11. Bredmossen, hollow; *Eriophorum vaginatum, Scheuchzeria palustris, Sphagnum cuspidatum, balticum, tenellum,* etc.

204. Roshultsmyren, hollow; *Eriophorum vaginatum, Myrica gale, Sphagnum magellanicum, tenellum, cuspidatum,* etc.

203. Not far from preceding but under *Eriophorum angustifolium* and close to *Narthecium ossifragum* (these two plants do not normally grow in ombrotrophic bogs in Sweden, as they do in W. Europe; in Sweden *Myrica* is a bog-plant only in the S.W.).

196. Skåne, Skanörs ljung (near no. 197, Table 1), a wet depression with, e.g., *Erica tetralix, Molinia coerulea, Carex panicea, Rhynchospora alba* and *fusca, Deschampsia setacea.*

3. Dalarna, Garpenberg, Igeltjärn. Quaking poor fen on a tarn. *Carex limosa, C. lasiocarpa, Menyanthes, Scheuchzeria, Rhynchospora alba, Eriophorum vaginatum, Sphagnum apiculatum, Dusenii, papillosum, rubellum,* etc. Wet, very soft and almost unhumified peat.

9. Bredmossen, the »lagg» or fen zone between the bog and the adjacent mineral soil. *Carex lasiocarpa, rostrata, limosa, nigra, Sphagnum Dusenii, apiculatum,* etc.

170. Dalarna, Lima, S.W. shore of Lake Tisjön, strongly sloping and flushed fen. *Menyanthes, Carex rostrata, Sphagnum pulchrum, Lindbergii,* etc.

169. Not far from preceding. Strongly flushed upper margin of sloping fen. *Menyanthes, Carex chordorrhiza, nigra, canescens, magellanica, Equisetum silvaticum, Pedicularis sceptrum-carolinum* (exceptional in poor fen!) *Sphagnum parvifolium, centrale, riparium, teres,* etc.

174. Örvikskölen, E. shore of Lake Tisjön, slightly sloping fen (intermediate between poor and rich as to species composition), with iron ochre deposits. *Molinia, Trichophorum caespitosum, Carex dioeca, Selaginella selaginoides, Sphagnum warnstorfianum, parvifolium, subfulvum,* etc. — Records from nos. 170 and 174 in Malmer & Sjörs 1955 (p. 55).

5. Dalarna, Garpenberg, Fransbo. Swamp forest with spruce, *Molinia, Carex vaginata,* etc., see Samuelsson 1960 (p. 105 and Table X no. 1).

14. Dalarna, Garpenberg, Rafshyttan. Rich swamp forest forming margin of a small fen, no. 15. Rich flora, e.g. *Picea, Alnus glutinosa* and *incana, Salix pentandra* and *aurita, Rhamnus frangula, Crepis paludosa, Filipendula ulmaria, Carex vaginata, echinata, flava, dioeca, Parnassia palustris, Cirsium palustre, Mnium Seligeri, Calliergonella cuspidata, Climacium dendroides, Sphagnum warnstorfianum.* Highly decomposed woody fen peat.

15. Same locality, open centre of the fen. *Carex lasiocarpa, panicea, chordorrhiza, limosa, Trichophorum alpinum, Peucedanum palustre, Utricularia intermedia, Campylium stellatum, Sphagnum warnstorfianum, Drepanocladus intermedius, Scorpidium scorpioides,* etc. Less decomposed wet peat.

142. Jämtland, Frostviken, between Lakes Jormvattnet and Blåsjön, subalpine region, sloping, strongly flushed fen. *Trichophorum caespitosum, Bartsia alpina, Molinia, Thalictrum alpinum, Carex vaginata, capillaris, flava, Viola biflora, Ranunculus acris, Drepanocladus intermedius, Campylium stellatum,* etc. (rich flora). Shallow, strongly decomposed peat on sandy till, which is waterlogged, almost free from humus and not podsolized.

140. Jämtland, Hammerdal, Fyrås, Vikbokälen. Rich wet spruce forest; *Geranium silvaticum, Rubus saxatilis, Vaccinium vitis-idaea, Anemone hepatica,* some *Aconitum septentrionale,* hundreds of flowering *Cypripedium calceolus,* etc.; *Rhytidia-*

delphus triquetrus and other mosses. Shallow (10—18 cm deep), peaty humus with F and H zones (the former 3 cm; sample from the latter, taken between 3 and 7 cm); the humus resting on somewhat clayey till.

163. Jämtland, Hammerdal, Forsflon (between Finnboriset and Lake Solbergsvattnet). Centre of fen but with scattered trees, very rich vegetation with much *Cypripedium, Filipendula ulmaria, Carex dioeca, Equisetum palustre, Crepis paludosa, Saussurea alpina, Sphagnum warnstorfianum, Tomentypnum nitens,* etc. (38 vascular species noted); on fairly deep peat.

162. Wooded margin of preceding fen; site for *Epipogium aphyllum.* 35 vascular species and 17 mosses noted, e.g. *Filipendula ulmaria, Crepis paludosa, Saussurea alpina, Listera cordata, Coeloglossum viride, Sphagnum warnstorfianum, Mnium* spp., *Philonotis fontana, Tomentypnum nitens, Helodium Blandowii.* 35 cm of peat, lower part woody, upper part (sample) medium decomposed.

137. Between Fyrås and Änge, fen-meadow with *Bartsia alpina.* Other plants, e.g., *Equisetum palustre, scirpoides, Deschampsia caespitosa, Eriophorum latifolium, Carex capillaris, vaginata, Saussurea alpina, Gymnadenia conopsea, Paludella squarrosa, Mnium Seligeri, Tomentypnum nitens, Rhytidiadelphus triquetrus.* About 30 cm of moist peat with slight mull structure in upper part (sample between 3 and 7 cm).

155. Fyrås, near Blekmyrbäcken. Sloping meadow-fen, very rich in species, e.g. *Molinia, Filipendula ulmaria, Crepis paludosa, Potentilla erecta, Pedicularis sceptrum-carolinum, Polygala amarella, Carex flava, capillaris, vaginata, capitata, Polygonum viviparum, Tomentypnum nitens,* near-by also *Ophrys insectifera.* About 30 cm of peat, lower part calcareous.

146. Jämtland, Hammerdal, Änge. Sloping wet meadow-fen, very rich in species, e.g. much *Gymnadenia conopsea, Carex dioeca, Saussurea alpina, Equisetum scirpoides, Thalictrum alpinum, Listera ovata, Carex capillaris, Primula farinosa, Eriophorum latifolium, Tomentypnum nitens, Cratoneurum falcatum.* About 5—8 cm of peat on a mixture of calcareous tufa and wet clayey marl.

152. Fyrås, Blekmyrbäcken. Scanty but rich vegetation, e.g. *Polygonum viviparum, Deschampsia caespitosa, Carex capillaris, Anemone nemorosa, Climacium dendroides.* Only 2—3 cm of peaty humus on pure lime deposited from spring water.

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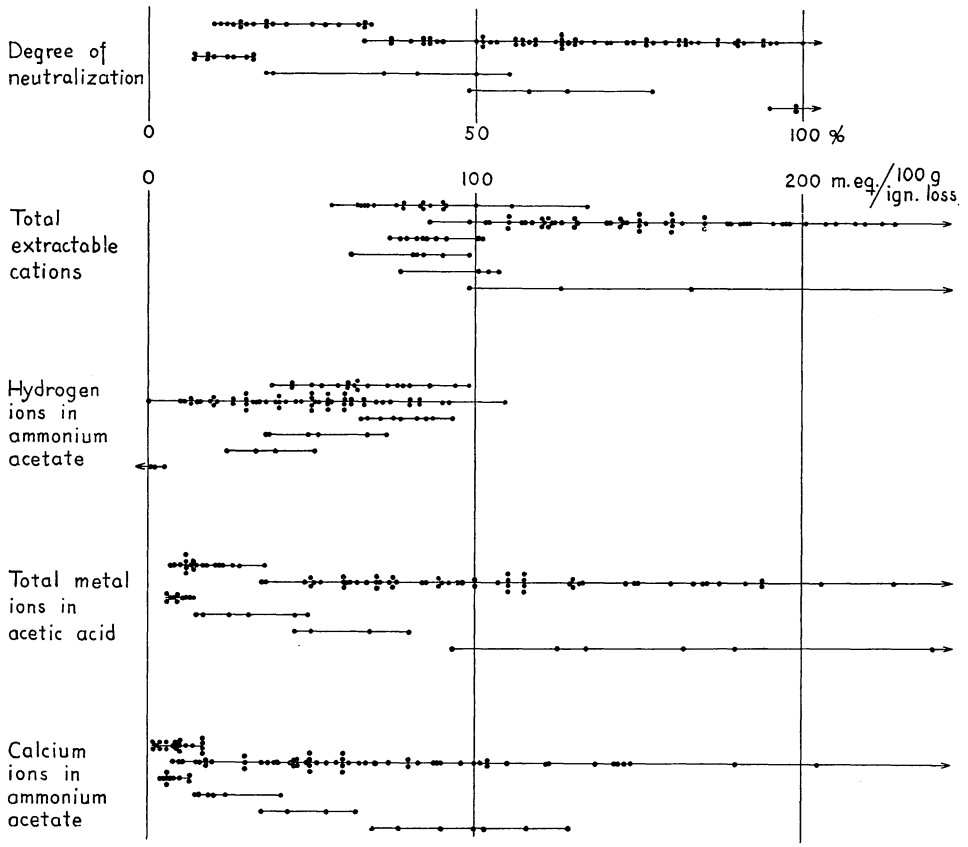

Fig. 7. Five properties of the humus samples, shown for six types of humus layer. In each group the rows represent (1) mor, (2) mull, (3) ombrotrophic (bog) peat, (4) minerotrophic peat from poor fen, (5) do. from moderately rich fen, (6) do. from extremely rich fen. In (2) the mull values in Sjörs 1954 (Table 13) are included. All values refer to dried samples, except a few cases Ca^{2+} had been determined only in fresh samples. The arrows represent calcareous soils from which carbonate was dissolved by the extractants, and thus non-exchangeable calcium ions were released in addition to exchangeable ions. In extremely rich fen, the ammonium acetate treatment had not dissolved much carbonate Ca^{2+}, contrary to acetic acid which gave some very high calcium values (see Table 4).

Summary

Samples, usually of known volume, have been obtained from the humus layer of Swedish natural soils, representing a great variety of sites and covered by various types of natural or semi-natural vegetation. The types of humus layer considered are mor (Table 1 p. 44), mull (Tables 2 p. 46 and 3 p. 48), and superficial peat (Table 4 p. 50). Extraction analyses have been made on both fresh and dried samples (see Figs. 1 and 2). The chemical properties determined (see Tables) are given in relation to 100 g humus (as ignition loss), and to 1 l of volume. No great differences exist between these two ways of expression, for humus content per litre (see Fig. 6 and p. 30) varies only between about 150 and 35 g in the humus layer, the majority of cases falling close to 100 g (higher at medium humus percentage by weight).

There is a marked difference between mors and mulls in N, P, acidity, total extractable cations (ion exchange capacity), total extractable metal ions in excess over anions, and extractable Ca^{2+}, although some overlapping occurs (Fig. 7). The difference is particularly sharp in »degree of neutralization», with a boundary at 33—35 % for Swedish samples (Brown's method). As seen from Fig. 7, a number of mors are fully comparable to the ombrotrophic bog peats, notorious for their high acidity and low nutrient standard. There seems to exist a lower limit for total N in Swedish mulls at about 2.4 % of the organic matter. In peats, conditions are more variable. Total P and total extractable cations (ion exchange capacity) are similar in peats and mors. N is more variable in peat, depending greatly on the parent material. Acidity (particularly degree of neutralization), total metal ions, and extractable Ca^{2+} are (in Sweden) very clearly related to the vegetational sequence ombrotrophic bog - poor fen - moderately rich fen - extremely rich fen (see cited papers by Du Rietz). Potassium is low in almost all samples of peat, as well as in mors and most mulls.

Among the diagrams, Fig. 5 shows the relation between pH in water extract and percentage of »neutralization». Fig. 6 gives volume weight in relation to loss on ignition. From these data rough estimations of the porosity could be made (p. 29).

Table 1. Mor

Upper row: fresh sample. Lower row: dried sample. Left figure: in 100 g humus (as ignition loss). Right figure: in one litre of soil. The double figures represent determinations in 1 *N* acetic acid/1 *N* ammonium acetate extracts, respectively.

No.	Locality	Weight g/l	Loss on ign. %	N, g		P, mg Total		P, mg Egnér		pH	Neutr. %
	Boggy mountain moor										
130	Högåsen	—	—							—	—
			96.2							3.6	12
	Calluna heath										
183	Skanörs ljung, northern	—	—	—		—		—		—	
			24.3	2.0		66		5		3.9	
198	Do., central	—	—	—		—		—		5.5	—
			54.4	1.8		44		5		4.4	33
197	Do., southern, near sea	—	—	—		—		—		4.5	—
			15.5	2.8		168		19		4.7	29
202	Esmared heath	—	—	—	—	—	—	—	—	4.3	8
		164	68.7	1.8	2.1	102	115	11	13	4.4	19
206	Mästocka heath	—	—	—	—	—	—	—	—	4.4	22
		422	28.7	2.3	2.8	178	216	13	16	4.2	32
190	Vallarum »fälad»	—	—	—	—	—	—	—	—	—	—
		217	56.0	2.2	2.7	128	156	15	18	4.0	14
177	Kroppefjäll, on gneiss rock	—	—	—	—	—	—	—	—	—	—
		394	43.6	2.4	4.2	270	470	5	9	3.9	16
176	Do., richer flora	—	—	—	—	—	—	—	—	—	—
		362	31.7	3.0	3.5	350	400	5	6	4.2	27
	Pine lichen forest										
171	Tisjölandet	—	—							3.8	—
		99	92.8							3.8	18
145	Ramsele	—	—							4.4	—
		115	90.6							4.4	34
13	Hedåker	—	—	—	—	—	—	—	—	—	—
		160	87.8	1.5	2.2	87	123	7	10	3.9	14
	Spruce forest										
184	Nyteboda, Polytrichum	—	—	—	—	—	—	—	—	—	—
		72	96.0	1.2	0.8	77	53			4.1	11
185	Do., Hylocomium	—	—	—	—	—	—	—	—	—	—
		102	89.6	1.4	1.3	78	71	9	9	3.8	10
2	Garpenberg	—	—	—	—	—	—	—	—	4.6	—
		90	91.2	1.6	1.3	79	65	6	5	3.6	13
150	Fyrås	—	—							4.5	—
		74	91.4							4.6	33
	Birch woodland										
164	Tisjön	—	—							3.7	—
		90	94.3							3.8	18
	Beech forest										
182	Skäralid	—	—	—	—	—	—	—	—	—	—
		104	76.5	2.3	1.9	84	67	7	6	3.9	15
	Oak forest										
201	Skällsås	—	—	—	—	—	—	—	—	4.4	20
		137	83.4	2.0	2.2	122	140	21	24	—	21
186	Dyneboda	—	—	—	—	—	—	—	—	—	—
		225	52.7	2.5	2.9	156	182	18	21	4.1	25

Extractable cations in milliequivalents								K+ m.eq. Egnér
Total	H+	Metal (excess)	Ca^{2+}	Mg^{2+}	Na^+	K^+		
—	—	—	— —					
83	73	10	6 / 8					
								—
								1.7
—	—	—	— —		— —	— —		—
56	38	18	11 / 10		1.0 / 0.6	1.9 / 1.6		1.2
—	—	—	— —		— —	— —		—
90	64	26	26 / 17		1.4 / 1.1	2.4 / 2.4		1.7
65 73	60 67	5 6	8 / 11 9 / 12	4 / 5 5 / 6	0.4 0.4	2.3 2.6		— —
76 85	61 69	15 16	8 / 6 9 / 7	— — — —	0.3 / 0.3 0.3 / 0.4	2.3 / 2.7 2.6 / 3.1		2.2 2.5
68 82	53 64	15 18	7 / 8 8 / 10	7 / 6 9 / 8	0.2 / 0.4 0.2 / 0.4	2.0 / 2.7 2.4 / 3.2		— —
86 104	58 70	28 34	14 / 9 17 / 11	— — — —	0.3 / 0.5 0.4 / 0.6	3.6 / 3.3 4.3 / 3.9		2.3 2.8
— —	— —	— —	— —		— —	— —		— —
100 121	86 105	14 16	7 / 3 8 / 4		0.5 / 0.4 0.6 / 0.5	2.9 / 3.4 3.5 / 4.1		2.4 3.0
— —	— —	— —	— —		— —	— —		— —
111 192	94 162	17 30	5 / 6 8 / 11		0.5 / 0.3 0.9 / 0.5	1.0 / 1.3 1.7 / 2.3		1.2 2.0
— —	— —	— —	— —		— —	— —		— —
134 153	98 112	36 41	14 / 17 16 / 20		0.3 / 0.6 0.4 / 0.7	1.8 / 2.6 2.0 / 3.0		1.6 1.9
— —	— —	— —	— —		— —	— —		
65 59	53 49	12 11	6 / 9 6 / 9		0.2 / 0.4 0.2 / 0.4	3.2 / 3.7 / 3.0 / 3.4		
— —	— —	18 19	12 / 14 13 / 15		— —	— —		
67 69	44 46	23 23	17 / 17 17 / 17		0.2 0.2	2.9 3.0		
— —	— —	— —	— —	— —	— —	— —		— —
90 126	78 109	12 17	17 24	1 1	0.5 0.7	1.7 2.4		1.8 2.6
— —	— —	— —	— —		— —	— —		
69 48	61 42	7 5	3 / 2 2 / 1		0.7 / 0.6 0.5 / 0.4	1.9 / 2.1 1.3 / 1.4		
— —	— —	— —	— —		— —	— —		— —
84 77	76 70	8 7	3 / 2 3 / 2		0.4 / 0.5 0.4 / 0.4	2.1 / 2.1 1.9 / 1.9		1.7 1.6
— —	93 77	— —	14 11	3 2	1.2 1.0	1.7 1.4		— —
91 75	80 65	12 9	— —	— —	— —	— —		2.0 1.7
— —	— —	34 23	14 / 16 10 / 11		— —	— —		
66 44	44 29	22 15	10 / 12 7 / 8		0.3 0.2	6.0 4.0		
— —	— —	— —	— —		— —	— —		
78 66	64 54	14 12	6 / 10 5 / 9		0.4 / 0.4 0.4 / 0.3	3.2 / 3.6 2.7 / 3.1		
— —	— —	— —	— —		— —	— —		— —
78 63	67 53	12 9	8 / 10 7 / 8		0.4 / 0.5 0.4 / 0.4	1.7 / 1.8 1.4 / 1.4		1.4 1.1
62 71	50 57	12 14	6 / 6 7 / 7	7 / 4 7 / 5	0.2 / 0.3 0.2 / 0.4	0.6 / 2.1 0.7 / 2.4		— —
64 73	50 58	13 15	5 / 4 6 / 5	— — — —	0.5 / 0.3 0.5 / 0.4	3.4 / 3.6 3.9 / 4.1		3.0 3.5
— —	— —	— —	— —		— —	— —		— —
84 99	63 74	21 25	7 / 4 8 / 5		0.5 / 0.5 0.5 / 0.6	3.7 / 3.5 4.4 / 4.1		3.1 3.7

Table 2. Forest mull, and related types of humus

Upper row: fresh sample. Lower row: dried sample. Left figure: in 100 g humus (as ignition loss). Right figure: in one litre of soil. The double figures represent determinations in 1 *N* acetic acid/1 *N* ammonium acetate extracts, respectively.

No.	Locality	Weight g/l	Loss on ign. %	N, g		P, mg Total		P, mg Egnér		pH	Neutr. %
	Spruce forest w. low herbs	—	—	—	—	—	—	—	—	5.3	—
4	Garpenberg, Bengtsbo ...	568	15,5	3.7	3.3	290	260	8	7	4.5	37
6	Garpenberg, Fransbo ...	—	—	—	—	—	—	—	—	6.1	—
		274	31.8	2.8	2.4	200	176	1	1	5.0	65
	Under Sorbus aucuparia	—	—	—	—	—	—	—	—	5.7	—
173	Bodarna, Geranium silv.	569	22.3	3.1	3.9	470	590	7	9	5.2	59
	Subalpine birch woodland	—	—	—	—	—	—	—	—	5.6	—
141	Jorm, Trollius, Vacc. myrt.	271	46.4	3.6	4.5	340	420	8	11	5.2	63
	Mixedwood on alum shales	—	—	—	—	—	—	—	—	5.1	—
154	Fyrås, very dark mull ...	185	54.5	2.5	2.5	280	280	21	21	4.9	52
153	Do., subsoil of 154	—	—	—	—	—	—	—	—	6.2	—
		1 137	18.9	1.4	3.0	540	1 160	12	25	5.6	76
136	Do., Carex atrata loc. ...	—	—	—	—	—	—	—	—	—	—
		644	19.6	3.0	3.8	350	440	9	11	5.8	82
149	Do., Aconitum, Milium ...	—	—	—	—	—	—	—	—	6.5	—
		665	21.2	3.3	4.5	760	1 070	5	7	5.8	94
135	Do., very tall Aconitum ...	—	—	—	—	—	—	—	—	—	—
		500	23.7	3.9	4.7	530	630	11	13	7.2	100
	Spruce forest w. tall herbs	—	—	—	—	—	—	—	—	6.4	—
143	Jormlien, Aconitum	477	22.5	2.4	2.6	480	520	4	4	6.4	90
	Beech forest	—	—	—	—	—	—	—	—	—	—
188	Brotorpet	183	42.7	2.6	2.0	129	102	15	11	4.2	42
200	Frodeparken	—	—	—	—	—	—	—	—	4.6	35
		664	15.0	2.9	2.9	280	280	12	12	4.8	37
181	Anklam	—	—	—	—	—	—	—	—	—	—
		674	6.9	3.7	1.7	570	260	13	6	4.8	44
180	Lyckås	—	—	—	—	—	—	—	—	—	—
		694	7.9	3.4	1.9	870	480	17	9	5.2	64
189	Forsakar	—	—	—	—	—	—	—	—	—	—
		453	13.5	2.4	1.4	530	330	24	15	5.7	73
	Hazel grove	—	—	—	—	—	—	—	—	5.3	—
1	Garpenberg, Hässlen	726	13.8	3.4	3.4	350	350	6	6	4.8	42
	Mixed hardwood forest	—	—	—	—	—	—	—	—	6.1	—
7	Realsbo hage, with ash ...	614	13.6	3.5	2.9	280	230	3	2	4.9	51
191	Dalby hage, beech, Mercur.	—	—	—	—	—	—	—	—	6.1	69
		850	10.1	3.7	3.1	700	600	34	29	5.4	70
207	Do., elm, Mercurialis	—	—	—	—	—	—	—	—	7.2	93
		666	12.0	3.0	2.4	630	510	55	44	6.6	94
179	Örup, elm, Mercurialis ...	—	—	—	—	—	—	—	—	—	—
		827	7.9	3.7	2.4	1 090	710	47	31	6.7	96
208	Fågelsång, Mercurialis ...	—	—	—	—	—	—	—	—	6.2	73
		525	20.0	3.1	3.3	620	650	16	17	—	79
193	Do., Petasites albus	—	—	—	—	—	—	—	—	7.0	100
		774	11.9	3.1	2.9	640	590	23	21	6.8	over
	Alnus incana wet woodland	—	—	—	—	—	—	—	—	6.0	—
8	Hässlen	347	45.7	3.1	5.0	270	430	3	4	5.1	59
	Alnus glutinosa wet woodland	—	—	—	—	—	—	—	—	—	—
187	Kasseboda	509	19.7	3.1	3.1	450	450	6	6	4.8	43
192	Dalby hage	—	—	—	—	—	—	—	—	6.6	88
		292	39.8	4.0	4.6	350	410	14	16	7.0	87

Extractable cations in milliequivalents																				K+ m.eq. Egnér	
Total		H+		Metal (excess)		Ca^{2+}				Mg^{2+}				Na+				K+					
—	—	120	106	—	—		46		40		10		9		2.4		2.1		2.1		1.8	—	—
131	116	83	73	48	42		—		—		—		—		—		—		—			1.4	1.3
—	—	51	44	—	—		45		40		8		7		1.1		0.9		1.1		0.9	—	—
141	123	50	43	92	80		—		—		—		—		—		—		—			0.9	0.8
—	—	—	—	—	—	—	—	—	—					—	—	—	—	—	—	—	—	—	—
114	145	47	60	67	85	43 /	37	54 /	47					0.5 /	0.5	0.6 /	0.6	2.2 /	2.7	2.8 /	3.4	2.2	2.7
—	—	—	—	75	95	39 /	35	49 /	44						—		—	—	—	—	—	—	—
120	152	45	57	75	95	39 /	39	49 /	49						0.5		0.6	4.3 /	3.7	5.4 /	4.6	3.3	4.2
—	—	—	—	66	67	50 /	50	50 /	51						—		—	—	—	—	—	—	—
103	104	50	50	53	54	56 /	67	57 /	67						0.3		0.3	3.5 /	4.4	3.5 /	4.4	2.3	2.3
—	—	—	—	92	197	83 /	88	178 /	189						—		—	—	—	—	—	—	—
110	236	26	57	84	179	91 /	89	197 /	191						0.3		0.7	1.1 /	1.9	2.3 /	4.0	1.6	3.4
—	—	—	—	—	—	97 /	91	122 /	115						—		—		—		—	—	—
196	248	36	45	160	203	94 /	74	119 /	94						0.6		0.8		4.8		6.0	4.0	5.1
—	—	—	—	134	183	109 /	109	148 /	148									—	—	—	—	—	—
201	273	13	17	188	256	130 /	104	177 /	142									4.1	5.9	5.6 /	8.0	3.6	5.0
—	—	—	—	—	—	219 /	202	251 /	240						—		—		—		—	—	—
228	270	0	0	228	270	199 /	180	235 /	213						0.5		0.6		2.3		2.7	2.1	2.4
—	—	—	—	148	158	112 /	102	123 /	112						—		—	--	—	—	—	—	—
191	204	20	21	171	183	101 /	100	109 /	108						0.4		0.4	2.4 /	1.8	2.6 /	2.0	1.6	1.7
—	—	—	—	—	—	—	—	—	—					—	—	—	—	—	—	—	—	—	—
86	67	51	40	35	27	20 /	16	15 /	12					0.4 /	0.3	0.3 /	0.2	4.9 /	4.7	3.9 /	3.7	3.4	2.7
92	92	60	60	32	32	11 /	12	11 /	12	15 /	6	15 /	6	0.6 /	0.4	0.6 /	0.4	2.5 /	1.9	2.5 /	1.9	—	—
98	98	62	62	36	36	—	8	—	8	—	—	—	—	0.6 /	0.7	0.6 /	0.7	3.1 /	2.7	3.1 /	2.7	1.8	1.8
—	—	—	—	—	—	—	—	—	—						—		—	—	—	—	—	—	—
163	75	92	42	71	33	44 /	46	20 /	22						0.8		0.4	3.5 /	2.6	1.6 /	1.2	2.5	1.2
—	—	—	—	—	—	—	—	—	—						—		—	—	—	—	—	—	—
181	99	66	36	115	63	86 /	90	47 /	49						0.9		0.5	11.6 /	4.6	6.4 /	2.5	4.6	2.5
—	—	—	—	—	—	—	—	—	—					—	—	—	—	—	—	—	—	—	—
122	75	33	20	89	55	71 /	58	43 /	35					0.6 /	0.9	0.4 /	0.5	5.4 /	5.7	3.3 /	3.5	3.8	2.3
—	—	144	144	—	—		62		62		4		4		2.8		2.8		4.0		4.0	—	—
144	144	83	83	61	61		—		—		—		—		—		—		—			2.2	2.2
—	—	91	76	—	—		30		25		3		3		1.0		0.9		2.3		1.9	—	—
146	122	72	60	74	62		—		—		—		—		—		—		—			3.1	2.6
170	147	52	45	118	101	—	—	—	—					—	—	—	—	—	—	—	—	—	—
184	158	55	48	129	110	124 /	122	106 /	104					2.2 /	1.7	1.9 /	1.4	7.2 /	8.3	6.2 /	7.1	4.7	4.0
158	126	11	9	147	117	165 /	181	132 /	145	28 /	25	22 /	20	0.7 /	1.0	0.5 /	0.8	8.8 /	11.4	7.1 /	9.1	—	—
194	155	11	9	183	146	167 /	144	133 /	115	—	—	—	—	2.1 /	1.4	1.7 /	1.1	10.4 /	9.4	8.3 /	7.5	5.6	4.5
—	—	—	—	—	—	—	—	—	—						—		—	—	—	—	—	—	—
292	190	13	8	279	182	224 /	205	146 /	134						1.8		1.2	11.7 /	9.5	7.6 /	6.2	8.9	5.8
123	128	33	34	90	94	76 /	93	79 /	98					0.6 /	0.8	0.6 /	0.9	7.0 /	9.1	7.5 /	9.5	—	—
145	152	30	31	115	121	95 /	65	100 /	74					1.5 /	0.5	1.6 /	0.5	5.8 /	5.1	6.0 /	5.4	3.1	3.3
207	191	0	0	207	191	—	—	—	—						—		—	—	—	—	—	—	—
—	—	weak.	neg.	270	250	286 /	252	263 /	232						1.3		1.2	4.9 /	3.3	4.5 /	3.0	2.4	2.2
—	—	48	77	—	—		52		83		2		4		1.0		1.6		0.7		1.1	--	—
104	165	42	67	62	98		—		—		—		—		—		—		—			0.8	1.3
—	—	—	—	—	—	—	—	—	—					—	—	—	—	—	—	—	—	—	—
117	117	66	66	51	51	7	18	7	18					1.0 /	0.6	1.0 /	0.6	2.2 /	1.9	2.2 /	1.9	1.5	1.5
135	157	17	19	118	138	—	—	—	—					—	—	—	—	—	—	—	—	—	—
152	177	19	22	133	155	131 /	104	152 /	121					0.9 /	0.9	1.1 /	1.0	1.4 /	1.8	1.6 /	2.0	0.8	0.9

Table 3. Mull from grassland and other open sites

Upper row: fresh sample. Lower row: dried sample. Left figure: in 100 g humus (as ignition loss). Right figure: in one litre of soil. The double figures represent determinations in 1 *N* acetic acid/1 *N* ammonium acetate extracts, respectively.

No.	Locality	Weight g/l	Loss on ign. %	N, g		P, mg Total		P, mg Egnér		pH	Neutr. %
	Grassland poor in herbs										
194	Dalby »fälad», grazed	—	—	—	—	—	—	—	—	4.7	—
		827	14.0	3.4	3.9	410	480	27	31	4.4	40
134	Fyrås, mown	—	—	—	—	—	—	—	—	—	—
		824	10.1	2.4	2.0	610	510	20	16	5.1	51
172	Bodarna, mown	—	—	—	—	—	—	—	—	5.3	—
		679	19.3	2.6	3.5	400	520	11	15	5.0	66
	Grassland rich in herbs										
151	Fyrås, Botrychium	—	—	—	—	—	—	—	—	5.4	—
		506	19.1	4.7	4.5	420	400	27	26	5.0	58
139	Do., Hypochoeris, podsol	—	—	—	—	—	—	—	—	—	—
		647	21.0	2.7	3.7	180	240	9	12	5.2	57
148	Do., do., brown earth	—	—	—	—	—	—	—	—	5.5	—
		668	18.1	3.1	3.7	500	610	7	8	5.0	62
147	Do., do., do., rich flora	—	—	—	—	—	—	—	—	6.0	—
		570	18.5	2.8	2.9	270	285	8	8	5.8	82
144	Do., Trifolium medium	—	—	—	—	—	—	—	—	6.2	—
		600	19.4	2.9	3.4	380	440	14	16	5.5	90
138	Do., Vicia silvatica	—	—	—	—	—	—	—	—	—	—
		781	16.3	3.1	4.0	230	290	7	10	6.6	95
129	Runmarö	—	—	—		—		—		—	—
			12.3	3.9		620		27		5.3	65
209	Mjö	—	—	—	—	—	—	—	—	5.0	74
		790	17.5	3.1	4.3	410	570	12	17	5.5	81
195	Vickleby alvar	—	—	—	—	—	—	—	—	—	—
		900	13.5	4.2	5.1	710	860	8	10	6.3	90
	Rock-meadow on gneiss										
175	Kroppefjäll, Geranium sanguineum	—	—	—	—	—	—	—	—	—	—
		413	37.1	4.4	6.7	420	645	8	13	5.3	53
178	Do., Vicia cassubica	—	—	—	—	—	—	—	—	—	—
		307	50.0	3.2	5.0	330	530	3	4	5.8	76
	Rock-meadow on limestone										
126	Runmarö, Sedum album	—	—	—		—		—		—	—
			42	3.7		490		19		6.6	91
127	Do., Festuca ovina, upper	—	—	—		—		—		—	—
			61	4.3		460		30		6.1	87
128	Lower mull of preceding	—	—	—		—		—		—	—
			31	4.3		1 530		146		6.0	83

Extractable cations in milliequivalents														K+ m.eq. Egnér	
Total		H+		Metal (excess)		Ca^{2+}		Na+		K+					
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
124	144	74	86	50	58	4 / 11	5 / 13	0.6	0.7	3.0 / 2.4	3.4 / 2.7			1.9	2.3
—	—	—	—	—	—	75 / 69	63 / 58	—	—	—	—			—	—
224	187	109	91	115	96	65 / 60	54 / 50	1.2	1.0	4.1	3.4			1.3	1.0
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
115	150	39	51	76	99	23 / 18	30 / 23	0.8 / 0.7	1.0 / 1.0	2.1 / 2.3	2.8 / 3.0			1.9	2.5
—	—	—	—	86	83	55 / 54	54 / 52	—	—	—	—	—	—	—	—
130	125	55	53	75	72	63 / 60	61 / 58	0.7	0.7	2.0 / 3.1	1.9 / 3.0			3.0	2.9
—	—	—	—	—	—	58 / 60	79 / 82			—	—	—	—	—	—
122	166	52	71	70	95	54 / 50	74 / 67			2.0 / 2.5	2.8 / 3.4			1.4	1.9
—	—	—	—	101	123	61 / 60	76 / 72	—	—	—	—			—	—
144	174	55	67	89	107	63 / 55	77 / 67	0.2	0.3	2.3	2.8			1.6	2.0
—	—	—	—	125	132	99 / 100	104 / 106	—	—	—	—	—	—	—	—
178	188	32	34	146	154	112 / 102	118 / 108	1.0	1.1	4.3 / 4.0	5.1 / 4.2			2.8	3.0
—	—	—	—	141	164	115 / 125	134 / 146	—	—	—	—	—	—	—	—
219	243	21	24	188	219	129 / 123	150 / 143	0.2	0.2	3.2 / 2.5	3.7 / 2.9			1.9	/ 2.2
—	—	—	—	—	—	147 / 133	187 / 169			—	—	—	—	—	—
216	274	10	12	206	262	164 / 146	209 / 186			4.2	5.3			3.4	4.3
—		—		—		—	—							—	
177		62		115		98 / 83								2.6	
131	181	34	47	97	134	126 / 118	174 / 163	0.6 / 0.5	0.8 / 0.7	1.5 / 1.6	2.1 / 2.3			—	—
183	253	34	47	149	206	143 / 88	198 / 121	1.6 / 1.1	2.2 / 1.6	2.2 / 1.9	2.8 / 2.6			0.6	0.8
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
195	240	20	25	175	215	152 / 143	180 / 170	3.1 / 1.1	3.8 / 1.3	3.2 / 2.5	3.9 / 3.0			1.7	/ 2.1
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
121	186	56	87	64	99	42 / 44	65 / 67	1.2 / 0.6	1.8 / 0.9	2.2 / 2.0	3.4 / 3.1			1.8	/ 2.7
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
126	193	30	46	96	147	58 / 49	89 / 76	0.5 / 0.5	0.7 / 0.7	1.6 / 2.0	2.5 / 3.1			1.6	/ 2.4
—		—		—		—	—							—	
182		15		167		91 / 137								1.7	
—		—		—		—	—							—	
123		16		107		104 / 96								1.6	
—		—		—		—	—							—	
158		26		132		185 / 148								1.6	

Table 4. Peat

Upper row: fresh sample. Lower row: dried sample. Left figure: in 100 g humus (as ignition loss). Right figure: in one litre of soil. The double figures represent determinations in 1 *N* acetic acid/1 *N* ammonium acetate extracts, respectively.

No.	Locality	Weight g/l	Loss on ign. %	N, g		P, mg				pH	Neutr. %
						Total		Egnér			
	Ombrotrophic bog										
165	Tisjökölen, pine bog	—	—							3,7	—
		85	97.5							3.8	10
166	Do., lacustrine	—	—					—	—	4.1	—
		80	94.7					6	7	4.2	16
10	Bredmossen, pine bog ...	—	—	—	—	—	—	—	—	4.4	—
		100	97.0	1.2	1.2	46	45	5	5	3.4	7
167	Tisjökölen, hummock ...	—	—							4.3	—
		41	98.7							4.0	13
12	Bredmossen, hummock ...	—	—	—	—	—	—	—	—	4.7	—
		65	97.2	0.9	0.6	35	22	4	3	3.7	9
205	Roshultsmyren, hummock	—	—	—	—	—	—	—	—	4.2	7
		121	96.3	1.5	1.7	47	54	8	9	4.0	9
168	Tisjökölen, hollow	—	—							4.1	—
		33	98.2							4.1	16
11	Bredmossen, hollow	—	—	—	—	—	—	—	—	4.6	—
		79	97.0	1.1	0.8	36	28	3	2	3.8	7
204	Roshultsmyren, hollow ...	—	—	—	—	—	—	—	—	4.0	0
		83	96.3	1.5	1.2	41	32	6	5	—	15
203	Do., Erioph. ang., Narth.	—	—	—	—	—	—	—	—	4.2	13
		162	93.4	2.5	3.7	59	89	7	11	3.9	12
	Poor (acid) fen	—	—	—	—	—	—	—	—	5.3	—
196	Skanörs ljung, depression	170	71.1	2.0	2.4	63	71	5	6	4.5	41
3	Igeltjärn, quagmire	—	—	—	—	—	—	—	—	5.2	—
		40	96.6	0.8	0.3	31	12	4	2	4.2	18
9	Bredmossen, »lagg»	—	—	—	—	—	—			5.3	—
		45	94.5	0.9	0.4	53	22			4.1	19
170	Tisjön, sloping, Menyanthes	—	—							5.3	—
		36	94.2							5.0	55
169	Do., do., Pedic. sceptrum-carolinum	—	—							5.1	—
		44	92.4							5.0	50
174	Do., intermediate fen	—	—							—	—
		37	95.4							4.7	36
	Moderately rich fen	—	—	—	—	—	—	—	—	5.7	—
5	Fransbo, wet forest	124	59.7	2.2	1.6	141	104	1	1	4.7	49
14	Rafshyttan, wooded fen	—	—	—	—	—	—	—	—	6.7	—
	margin	190	65.8	2.9	3.7	225	280	1	2	5.3	64
15	Rafshyttan, open fen	—	—	—	—	—	—	—	—	6.1	—
		86	81.1	2.4	1.7	115	80	2	2	5.3	58
142	Jorm, subalpine, Bartsia	—	—	—	—	—	—	—	—	5.8	—
		240	45.7	3.9	4.3	32	36	11	12	5.4	77
	Extremely rich fen, Fyrås	—	—	—	—	—	—	—	—	6.9	—
140	Wet forest, Cypripedium	186	82.9	2.0	3.1	109	182	14	21	6.8	99
163	Open fen, Cypripedium ...	—	—	—	—	—	—	—	—	7.3	—
		92	93.1	1.8	1.6	88	76	14	12	6.6	99
162	Wooded fen margin, Epipogium	—	—					—	—	6.8	—
		104	93.4					18	18	6.5	95
137	Fen-meadow, Bartsia	—	—	—	—	—	—	—	—	—	—
		233	63.5	2.4	3.6	180	270	2	4	6.5	over
155	Meadow-fen, Carex capitata	—	—					—	—	7.5	—
		139	89.1					11	14	6.4	over
146	Do., Gymnadenia, on lime	—	—							7.3	—
		34	84.9							7.0	over
152	Do., thin peat on lime ...	—	—	—	—	—	—	—	—	7.6	—
		213	70.5	3.5	5.3	200	300	16	23	7.0	over

Extractable cations in milliequivalents																				K+ m.eq. Egnér	
Total		H+		Metal (excess)		Ca^{2+}				Mg^{2+}				Na+				K+					
—	—	—	—	—	—	—	—	—	—					—	—	—	—	—	—	—	—		
85	71	77	64	8	7	3 /	8	2 /	7					0.9 /	0.4	0.7 /	0.3	2.2 /	2.6	1.9 /	2.2		
—	—	—	—	—	—	—	—	—	—					—	—	—	—	—	—	—	—		
79	59	67	50	12	9	12 /	13	9 /	10					0.4 /	0.4	0.3 /	0.3	1.2 /	1.9	0.9 /	1.4		
—	—	78	76	—	—		6		6		1		1		0.6		0.6		1.0		0.9		
91	88	85	82	6	6		—		—		—		—		—		—		—		—	1.9	1.8
—	—	—	—	—	—	—	—	—	—					—		—		—		—			
101	41	87	35	14	6	5 /	13	2 /	5					0.5		0.2		1.8		0.7			
—	—	—	—	—	—		—		—		—		—		—		—		—		—		
102	65	93	59	9	6		10		7		3		2		0.7		0.4		1.4		0.9	1.3	0.8
74	86	69	80	5	6	4 /	4	4 /	5	6 /	6	7 /	7	0.3 /	0.4	0.3 /	0.5	0.8 /	0.7	0.9 /	0.9	—	—
82	95	75	87	7	8	4 /	4	4 /	4	—	—	—	—	0.4 /	0.5	0.4 /	0.5	1.1 /	1.3	1.3 /	1.5	0.9	1.1
—	—	—	—	—	—	—	—	—	—														
84	27	71	23	13	4	5 /	6	2 /	2														
—	—	103	80	—	—		7		5		3		2		1.2		0.9		1.7		1.3	—	—
88	68	82	63	6	5		—		—		—		—		—		—		—		—	0.7	0.5
80	64	80	64	0	0	6 /	7	5 /	6	10 /	11	8 /	9	0.6 /	0.7	0.5 /	0.6	0.7 /	0.6	0.6 /	0.5	—	—
77	61	65	52	11	9	6 /	6	5 /	5	—	—	—	—	0.5 /	0.4	0.4 /	0.3	0.7 /	0.6	0.5 /	0.5	0.5 /	0.4
69	105	60	91	9	14	4 /	5	7 /	8	5 /	6	8 /	8	0.3 /	0.5	0.4 /	0.7	0.4 /	0.6	0.6 /	1.0	—	—
74	112	65	99	9	13	4 /	5	6 /	8	—	—	—	—	0.3 /	0.5	0.4 /	0.7	0.7 /	0.9	1.1 /	1.4	0.7 /	1.0
—	—	—	—	—	—	—	—	—	—					—	—	—	—	—	—	—	—	—	—
62	75	37	44	25	31	14 /	16	17 /	20					1.1 /	0.9	1.4 /	1.1	1.4 /	1.4	1.7 /	1.7	0.9 /	1.1
—	—	80	30	—	—		20		8		6		2		1.8		0.7		1.4		0.5	—	—
82	32	67	26	15	6		—		—		—		—		—		—		—		—	2.2	0.8
—	—	78	33	—	—		15		6		3		1		1.5		0.7		3.6		1.5	—	—
90	38	73	31	17	7		—		—		—		—		—		—		—		—	3.4	1.4
—	—	—	—	—	—	—	—	—	—														
81	27	36	12	45	15	27 /	41	9 /	14														
—	—	—	—	—	—	—	—	—	—					—	—	—	—	—	—	—	—		
98	40	49	20	49	20	24 /	24	10 /	10					0.9 /	1.1	0.4 /	0.4	3.0 /	2.7	1.2 /	1.1		
—	—	—	—	—	—	—	—	—	—														
84	29	52	18	31	11	22 /	19	7 /	7														
—	—	63	47	—	—		43		33		8		6		1.8		1.4		1.3		1.9	—	—
101	76	51	39	50	37		—		—		—		—		—		—		—		—	1.4	1.0
—	—	37	47	—	—		64		80		3		4		1.2		1.5		1.6		2.0	—	—
107	134	39	49	68	85		—		—		—		—		—		—		—		—	1.1	1.3
—	—	30	21	—	—		35		24		5		3		1.6		1.1		1.7		1.2	—	—
77	54	33	23	45	31		—		—		—		—		—		—		—		—	0.9	0.6
—	—	—	—	—	—	62 /	44	68 /	48						—		—		—		—	—	—
104	111	24	26	80	88	56 /	55	62 /	61						0.5		0.6		2.0		2.2	1.7	1.8
—	—	—	—	—	—	113 /	111	174 /	171						—		—	—	—	—	—	—	—
166	256	2	3	164	253	129 /	100	199 /	155						0.2		0.3	2.3 /	2.9	3.5 /	4.5	1.6 /	2.5
—	—	—	—	—	—	138 /	166	119 /	143									—		—			
126	109	1	1	125	108	102 /	69	88 /	60									4.1		3.5			
—	—	—	—	—	—	110 /	120	107 /	116													—	—
98	95	5	5	93	90	82 /	77	80 /	75													1.9	1.8
		—	—	—	—	189 /	184	279 /	271						—		—	—	—	—	—	—	—
		weak.	neg.	240	354	172 /	129	255 /	190						0.4		0.5	1.8 /	2.1	2.7 /	3.1	1.6	2.4
		—	—	166	204	137 /	140	169 /	173									—		—		—	—
		weak.	neg.	134	166	115 /	90	142 /	112									2.3		2.9		1.4	1.7
		—	—	290	86	275 /	194	80 /	57														
		negative		180	52	137 /	116	40 /	34														
		—	—	313	468	244 /	175	367 /	257						—		—	—	—	—	—	—	—
		negative		582	870	318 /	108	478 /	159						0.3		0.4	4.0 /	2.4	6.0 /	3.7	1.6	2.4